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CHARACTER OF RANDOM
INLET PRESSURE FLUCTUATIONS
DURING FLIGHTS OF F-111A AIRPLANE

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0152184

1. Report No. NASA TM X-3540		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle CHARACTER OF RANDOM INLET PRESSURE FLUCTUATIONS DURING FLIGHTS OF F-111A AIRPLANE				5. Report Date May 1977	
				6. Performing Organization Code	
7. Author(s) William G. Costakis				8. Performing Organization Report No. E-9037	
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135				10. Work Unit No. 505-05	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546				13. Type of Report and Period Covered Technical Memorandum	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract Compressor face dynamic total pressures from four F-111 flights were analyzed. Statistics of the nonstationary data were investigated by analyzing the data in a quasi-stationary manner. Changes in the character of the dynamic signal are investigated as functions of flight conditions, time in flight, and location at the compressor face. The results, which are presented in the form of rms values, histograms, and power spectrum plots, show that the shape of the power spectra remains relatively flat while the histograms have an approximate normal distribution.					
17. Key Words (Suggested by Author(s)) Flow distortion Inlet pressure Inlet flow F-111 aircraft			18. Distribution Statement Unclassified - unlimited STAR Category 02		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 35	
				22. Price* A03	

CHARACTER OF RANDOM INLET PRESSURE FLUCTUATIONS DURING FLIGHTS OF F-111A AIRPLANE

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SUMMARY

Compressor face dynamic total pressures from four F-111 flights were analyzed. Statistics of the nonstationary data were investigated by treating the data in a quasi-stationary manner. This was achieved by analyzing short time segments. During these short time segments the data remained relatively constant. Changes in the character of the dynamic signal are investigated as functions of flight conditions, time in flight, and location at the compressor face. The results are presented in the form of rms values, histograms, and power spectrum plots. These results show that the shape of the power spectra remains relatively flat through the frequency range of the data and that the histograms exhibit an approximate normal distribution.

INTRODUCTION

The effect of steady-state total pressure distortion on stall margin has been well documented. It has become quite apparent that dynamic total pressure distortion at the compressor face can also decrease the stall margin. In general, the compressors are sensitive to a combination of steady-state and dynamic distortion. The manner in which these two types of total pressure distortion combine to effect the engine stall margin has become of great interest.

Some attempts have been made to correlate instantaneous distortion amplitudes with stall (e.g., refs. 1 to 3). Other studies have expressed the dynamic activity in terms of rms values. The rms values, then, are correlated to steady-state distortion at stall (and consequently to stall margin loss). Reference 4 shows that the steady-state distortion tolerance decreases as turbulence rms increases; in reference 5 the turbulence was transformed into an equivalent square wave pattern having the same effect on stability.

An index that correlated well with exhaust nozzle area of a turbofan engine is pre-

sented in reference 6. This index combined both steady-state and dynamic distortion (in the form of rms values) for the same angle of extent. With this index a clear boundary was established between the stall and the nonstall regions. A general conclusion on the validity of this method could not be made, however, because the data from this test were limited to a narrow band of engine speeds and one flight condition.

There is a need for a suitable index that can be used as a control signal in a scheme designed to avoid stall. An instantaneous index would appear to be the most logical control signal. Unfortunately, it has two serious drawbacks. First, the short interval between the stall-causing disturbance and the resulting stall do not allow sufficient time for a slowly moving controlled parameter to react. Second, a calculation of an instantaneous distortion index requires a large number of dynamic pressure signals. This requirement is impractical for an in-flight control. The process of selecting the maximum instantaneous distortion from such a large number of dynamic transducers is also costly and time consuming.

Some attempts to simplify this process through statistical analysis, using rms levels and power spectra, are described in references 7 to 10. The rms value of a dynamic signal could be used to account for its effects on stall if a correlation exists between the rms value and the highest peaks of the dynamic signal. The correlation must hold true for a wide range of flight conditions and locations at the compressor face. With such an index, corrective action could be taken before the stall-causing peak occurs. Thus, a control parameter would have time to act.

The purpose of this study was to determine whether rms values of nonstationary dynamic total pressure signals from four F-111 flight runs could be used to predict dynamic pressure peaks. A quasi-stationary approach was used by analyzing the data over short-increments of time. During these short increments of time the data remained relatively constant. If the rms values were to be used to predict the highest peaks expected, two items had to be determined: (1) the character of the dynamic signals, and (2) whether this character remains relatively unchanged for different flight conditions, locations at the compressor face, and time in flight. The results are presented in terms of power spectrum plots, histograms, and rms values.

SYMBOLS

f	frequency
$f(x_i)$	frequency of occurrence
h	total number of pressure classes
m_i	i th moment about mean value μ

N_1	engine speed, rpm
$N_1/\sqrt{\theta}$	corrected engine speed
n	total occurrence
$\Delta P_{T, rms}$	rms value of dynamic portion of total pressure, N/m^2 (psi)
rms	root mean square
s	skewness
W_c	corrected flow, kg/sec (lb/sec)
x_i	pressure class mark, N/m^2 (psi)
β_2	kurtosis
μ	mean value
σ	standard deviation

DESCRIPTION OF APPARATUS

Airplane

The F-111A airplane is a tactical fighter with variable sweep, high mounted wings. The test airplane was powered by two TF 30-P-1 engines. A more detailed description of the airplane and its propulsion system can be found in reference 3.

Instrumentation

The compressor face total pressure instrumentation (shown in fig. 1) consisted of eight high response rakes fitted with miniature differential pressure transducers. The rakes were a special type with an in-flight nulling capability to compensate for zero shifts of the transducer signal. The frequency response of the rakes was flat to 400 hertz. Details of the design and in-flight evaluation of the nulling rakes are described in reference 11.

Data Recording

The output signals were filtered electrically before digitizing. The cutoff frequency of the filter was 200 hertz. The filtered compressor signals were digitized by two pulse code modulation (PCM) systems at a rate of 400 samples per second. The output of the PCM systems was recorded on an onboard tape recorder.

DATA ANALYSIS

The data used in this analysis were recorded on a fourteen channel analog tape recorder. The tape was prepared by Dryden Flight Research Center from the original flight tapes. The recorded transducer locations are shown as solid symbols in figure 1. The response of these signals is limited to 200 hertz.

The purpose of this analysis is to determine whether the character of the dynamic portion of the compressor face pressure signals remains the same (1) for different flight conditions, (2) for different locations at the compressor face, and (3) for different times in flight.

The nonstationary data were analyzed in a quasi-stationary manner by analyzing short time increments of the data. The length of the time increments was 2 seconds. During these 2-second increments the data appear to be reasonably stationary. This conclusion was based on (1) visual observation of the data recorded on strip charts and (2) the examination of the time varying rms values of the signals. An HP 3400A true rms voltmeter was used for the latter.

Three 2-second segments of data were analyzed for each pressure signal. For convenience, the three segments will be identified as follows:

Segment A - Two seconds of data just prior to stall or the end of available data, if stall did not occur.

Segment B - Two seconds of data about the middle of the existing data.

Segment C - Two seconds of data at the beginning of the existing data.

The duration of the data used in this analysis varied from approximately 8.4 seconds for flight 43 to 21.2 seconds for flight 42.

The results are presented in the form of power spectrum plots, histograms, and rms values. The power spectrum plots were generated using an EMR 1510 real-time spectrum analyzer. The histograms and the rms values were obtained from an analog computer. A schematic of the analysis procedure is shown in figure 2.

One histogram from each flight was also fitted with a normal distribution. The mean and standard deviations of the histograms were determined using the following expressions:

Mean:

$$\mu = \frac{1}{n} \sum_{i=1}^h x_i f(x_i)$$

Standard deviation:

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^h (x_i - \mu)^2 f(x_i)}$$

The mean and standard deviations, then, were used to generate the normal distribution using the relationship

$$f(x_i) = \frac{1}{\sigma \sqrt{2\pi}} e^{-(1/2)[(x_i - \mu)/\sigma]^2}$$

The skewness and kurtosis of these histograms were also calculated using the following definitions:

Skewness:

$$s = \frac{3(\mu - \text{median})}{\sigma}$$

Kurtosis:

$$b_2 = \frac{M_4}{\sigma^4}$$

where

$$M_4 = \frac{1}{n} \sum_{i=1}^h (x_i - \mu)^4 f(x_i)$$

An illustration of the relationship between rms values, histograms, and power spectra of random noise signals is shown in figure 3. The histogram represents the fractional frequency of occurrence of the signal in each class interval. The boundaries of each class interval are shown by the dashed lines. The power spectrum indicates that the frequency content of the signal is from 0 to f_0 hertz.

RESULTS AND DISCUSSION

Data used in this analysis were obtained from NASA Dryden Flight Research Center. These data represent part of the data, which were used to study in-flight dynamic pressure phenomena, from F-111 flights. An extensive analysis of the entire flight data is summarized in reference 3. In this analysis we are only concerned with changes in the character of the dynamic signal as the location on the compressor face, the flight condition, and the time in flight change.

Data from four flight runs were analyzed. Flight conditions for these runs are summarized in table I. The data from flights 41, 42, and 43 included the recording of a compressor stall, but the flight 45 data did not include a stall.

The rms values of the dynamic pressure signals of each 2-second segment of the flight are shown in table II. There is a general increase in rms level as stall is approached for flights 41 and 43. The rms values for flight 42 decrease somewhat as the flight progresses from approximately 21 seconds before stall to about 11 seconds before stall. However, the rms values increase again as stall is approached to a somewhat higher overall level than before. In flight 45, some of the rms levels increase slightly while others decrease, thus resulting in no appreciable change in rms level as time proceeds.

Figures 4 to 7 show the power spectra of the dynamic total pressure signals from the four flight runs. The power spectrum for each of the six pressure signals around the face of the compressor is shown for each run. The shape of the power spectra was relatively flat for most of the data points presented in these figures. The power spectra of the signals from flight 45 decrease somewhat as the frequency is increased. The results from flight 45 also indicate the existence of a resonance at about 23 hertz. Reference 3 results indicate that this duct resonance was observed at Mach 2.25 and higher. The pressure signals from rake eight show a rolloff at a lower frequency than the others for all four flight runs. This may be due to a different corner frequency of the filter while recording the data.

Figures 8 to 11 show the histograms of these dynamic pressure signals. Histograms of the three 2-second segments of each signal are plotted. The distributions of these histograms appear to be symmetrical, and they possess the bell-like shape that is characteristic of a normal or Gaussian distribution.

In order to determine how closely these histograms approximate a Gaussian distribution, one histogram from each flight was selected and fitted with a Gaussian distribution. The histograms were scaled for unity area under the curve, and the mean and standard deviations were calculated and used in the expression for a normal distribution. The results are shown in figure 12. The results presented in this figure indicate that these histograms are approximated closely by a normal distribution. The mean value was nearly zero, while the skewness was small enough to be considered insignifi-

cant. The kurtosis has a value of 3 for a normal distribution. Two of the histograms had values somewhat lower than 3, while the other two had values somewhat higher than 3. These values are considered to be within the expected error of the kurtosis calculation. A significant error can occur in the calculation of the kurtosis because of the great effect of the extreme values of the frequency function $f(x_i)$ on this calculation. For example, the expected accuracy of $f(x_i)$ is considered to be within ± 0.001 . The two extreme values of $f(x_i)$ for flight 42 are both 0.001. When these two extreme values are considered in the calculation of kurtosis the value of kurtosis is 3.43. When they are excluded the value of the kurtosis becomes 3.21.

Another characteristic of normally distributed noise is that the ratio of the highest peaks to the rms values is approximately 3. In figure 13 the highest peaks observed in constructing the histograms are plotted against the rms values of the corresponding time segment. Data points from segments A and C were used in this plot. The results show a linear relationship with a crest factor (ratio of highest peaks to rms values) of 3.

CONCLUDING REMARKS

Compressor face dynamic total pressures from four F-111 flights were analyzed in a quasi-stationary manner. The following results were obtained:

1. The shape of the power spectra of the dynamic total pressure signals did not change appreciably for different flight conditions, locations at the compressor face, and time in flight. A resonance of approximately 23 hertz appeared in one of the flights.

2. Histograms of the magnitude of the dynamic total pressures indicated a fairly good normal distribution for all locations at the compressor face, flight conditions, and time in flight. Also, a linear relationship with a crest factor (ratio of highest peaks to rms values) of 3 was observed in accordance with theory for normally distributed data.

The results of this study indicate that if the rms values of dynamic pressure signals are calculated over short time segments they can predict the highest peaks expected within the segment when (1) the segment is chosen to be short enough so that the signal appears stationary within the segment, and (2) the character of the signal is consistent as shown by the previous results.

The flat power spectra shape and the normal distribution of the signals are highly desired characteristics. They can be very useful when implementing the distortion pattern synthesis methods, as well as in the formulation of simple distortion indices that can be used as the control signal in schemes designed to avoid stall.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 18, 1977,
505-05.

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TABLE I. - FLIGHT CONDITIONS

[Angle of attack, $\sim 4^\circ$ to 5° .]

Flight	Run	Mach	Altitude		Power setting, percent	Engine speed, N_1 , rpm	Corrected engine speed, $N_1/\sqrt{\theta}$	Corrected flow, W_c		Bleeds	
			km	ft				kg/sec	lb/sec	Seventh	Twelfth
41	11B	0.72	9.1	30 000	80	7730	8160	87.54	193	Closed	Closed
42	1JS	1.73	13.7	45 000	Maximum	9200	8530	92.53	204	Open	↓
43	3S	.9	9.1	30 000	Military	9650	9900	106.14	234	Closed	
45	13P2	2.32	14.3	47 000	Maximum	8470	6930	65.77	145	Open	

TABLE II. - RMS VALUES OF DYNAMIC PRESSURE SIGNALS

Time before stall, sec	Ring					
	3	3	3	3	3	5
	Rake					
	2	3	4	6	7	8
	Dynamic pressure signals, $\Delta P_{T, rms}$, N/cm ² (psi)					
Flight 41, run 11B						
2.4	0.044 (0.064)	0.047 (0.068)	0.064 (0.092)	0.106 (0.152)	0.072 (0.104)	0.099 (0.143)
6.6	.034 (.049)	.045 (.065)	.057 (.082)	.101 (.146)	.076 (.109)	.086 (.124)
12.8	.030 (.043)	.039 (.056)	.045 (.065)	.063 (.090)	.069 (.099)	.053 (.077)
Flight 42, run 1JS						
2.4	0.098 (0.141)	0.089 (0.128)	0.093 (0.134)	0.216 (0.311)	0.172 (0.247)	0.178 (0.256)
11.2	.068 (.097)	.074 (.106)	.069 (.100)	.197 (.284)	.140 (.202)	.140 (.201)
21.2	.083 (.112)	.089 (.128)	.078 (.112)	.261 (.376)	.169 (.243)	.158 (.227)
Flight 43, run 3S						
2.4	0.090 (0.113)	0.073 (0.105)	0.065 (0.094)	0.149 (0.215)	0.147 (0.212)	0.159 (0.229)
6.2	.055 (.079)	.050 (.072)	.064 (.092)	.118 (.171)	.106 (.152)	.131 (.189)
8.4	.051 (.074)	.044 (.064)	.064 (.092)	.126 (.182)	.090 (.130)	.118 (.171)
Flight 45, run 13P2						
^a 2.0	0.280 (0.404)	0.443 (0.637)	0.279 (0.401)	0.360 (0.518)	0.317 (0.456)	0.295 (0.425)
^a 8.8	.252 (.363)	.408 (.588)	.238 (.342)	.364 (.524)	.302 (.435)	.299 (.431)
^a 14.6	.257 (.370)	.426 (.613)	.248 (.356)	.374 (.538)	.320 (.462)	.306 (.440)

^aThese values are times before end of available data.

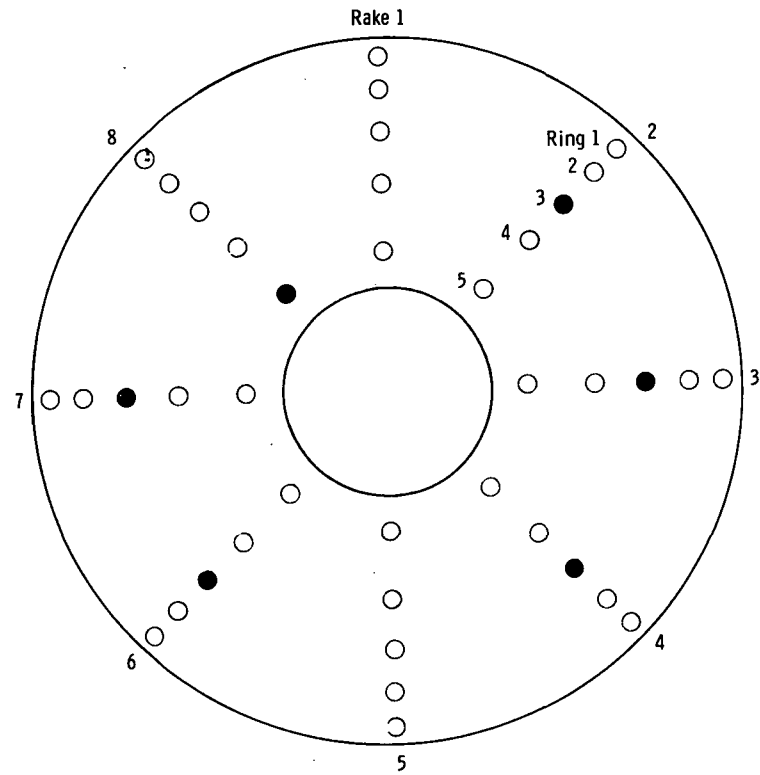


Figure 1. - Compressor face total pressure instrumentation. Solid symbols indicate total pressures used in this analysis.

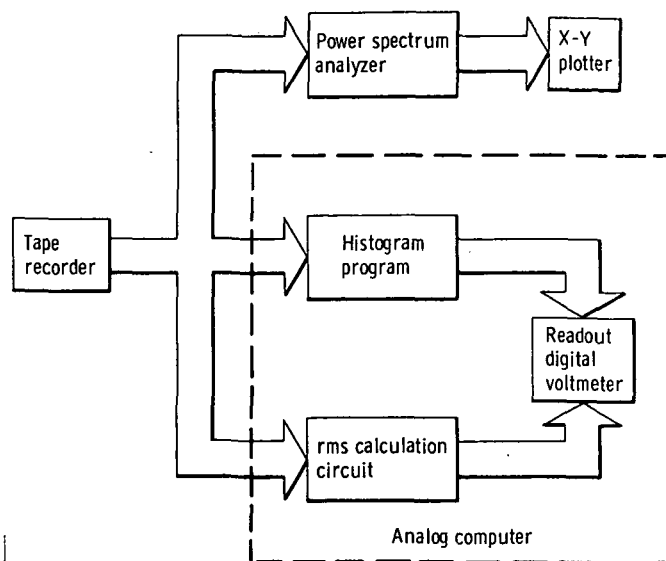


Figure 2. - Schematic of analysis procedure.

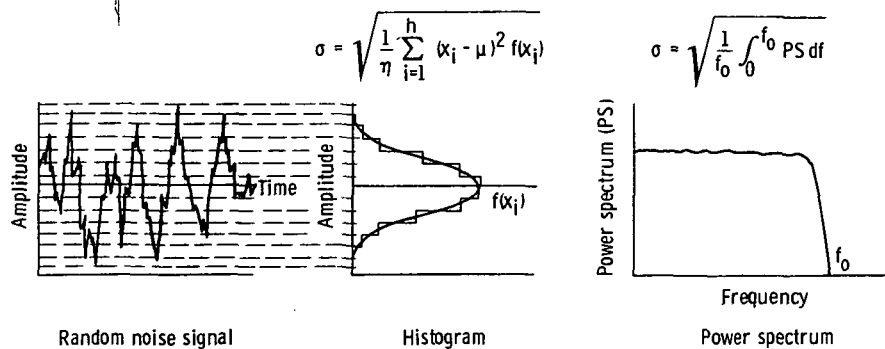


Figure 3. - Relationship between rms values, histograms, and power spectra of random noise signals.

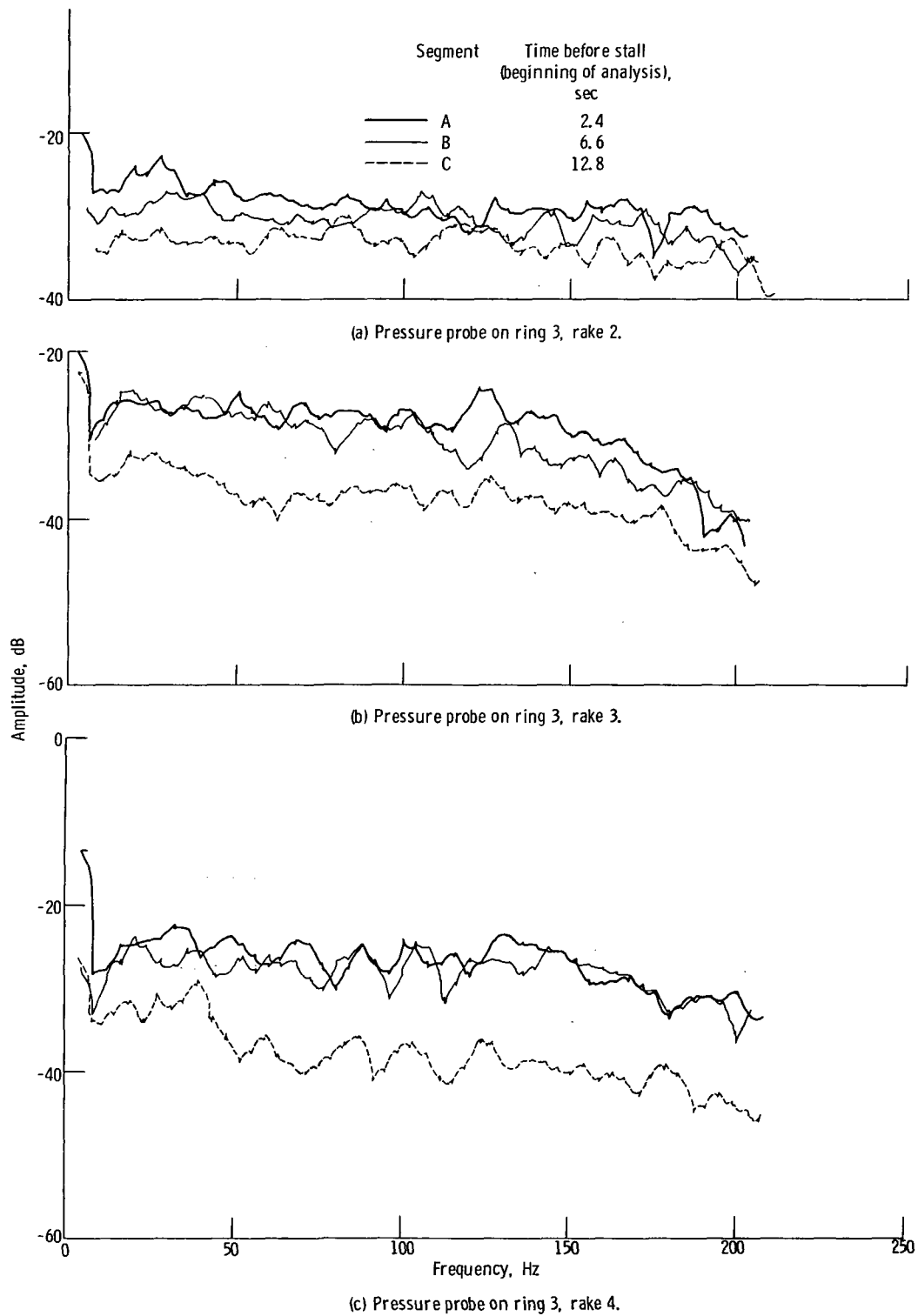


Figure 4. - Power spectra of compressor face total pressure at different times before stall. Flight 41; run 11B; analysis time, 2 seconds; maximum range, 0.220 newton per square centimeter rms (0.316 psi rms).

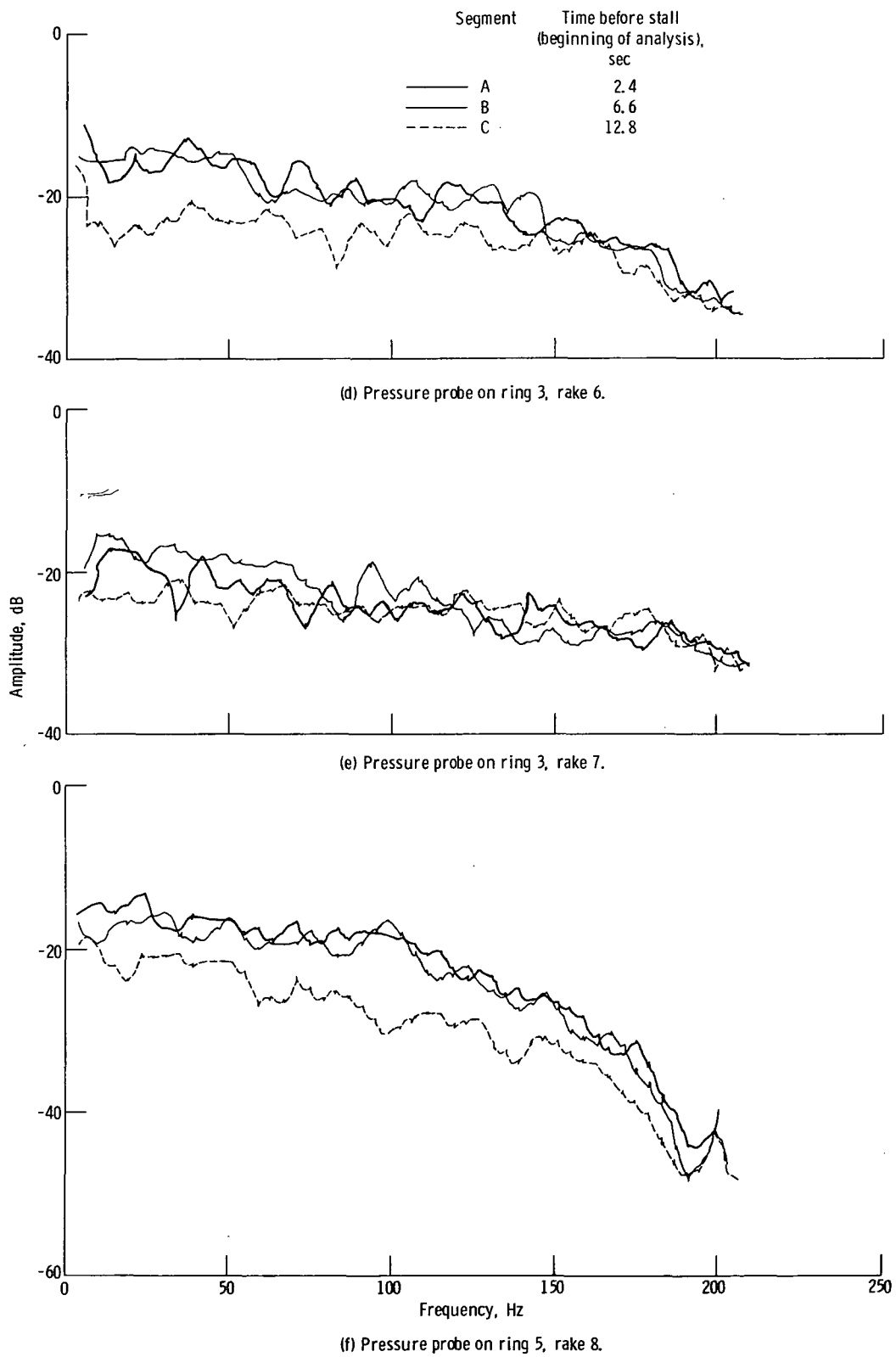


Figure 4. - Concluded.

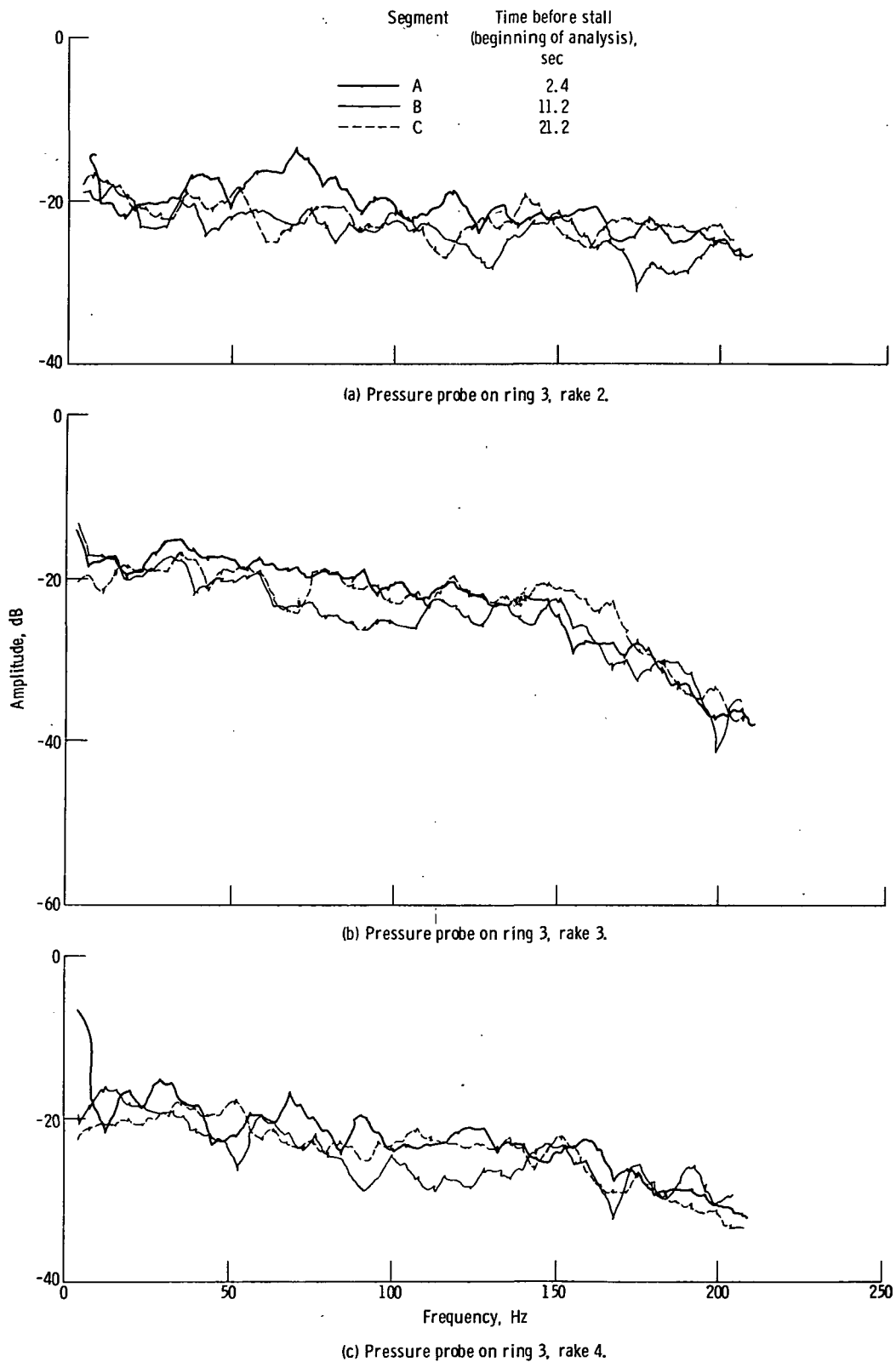


Figure 5. - Power spectra of compressor face total pressures at different times before stall. Flight 42, run 1JS; analysis time, 2 seconds; maximum range, 0.220 newton per square centimeter rms (0.316 psi rms).

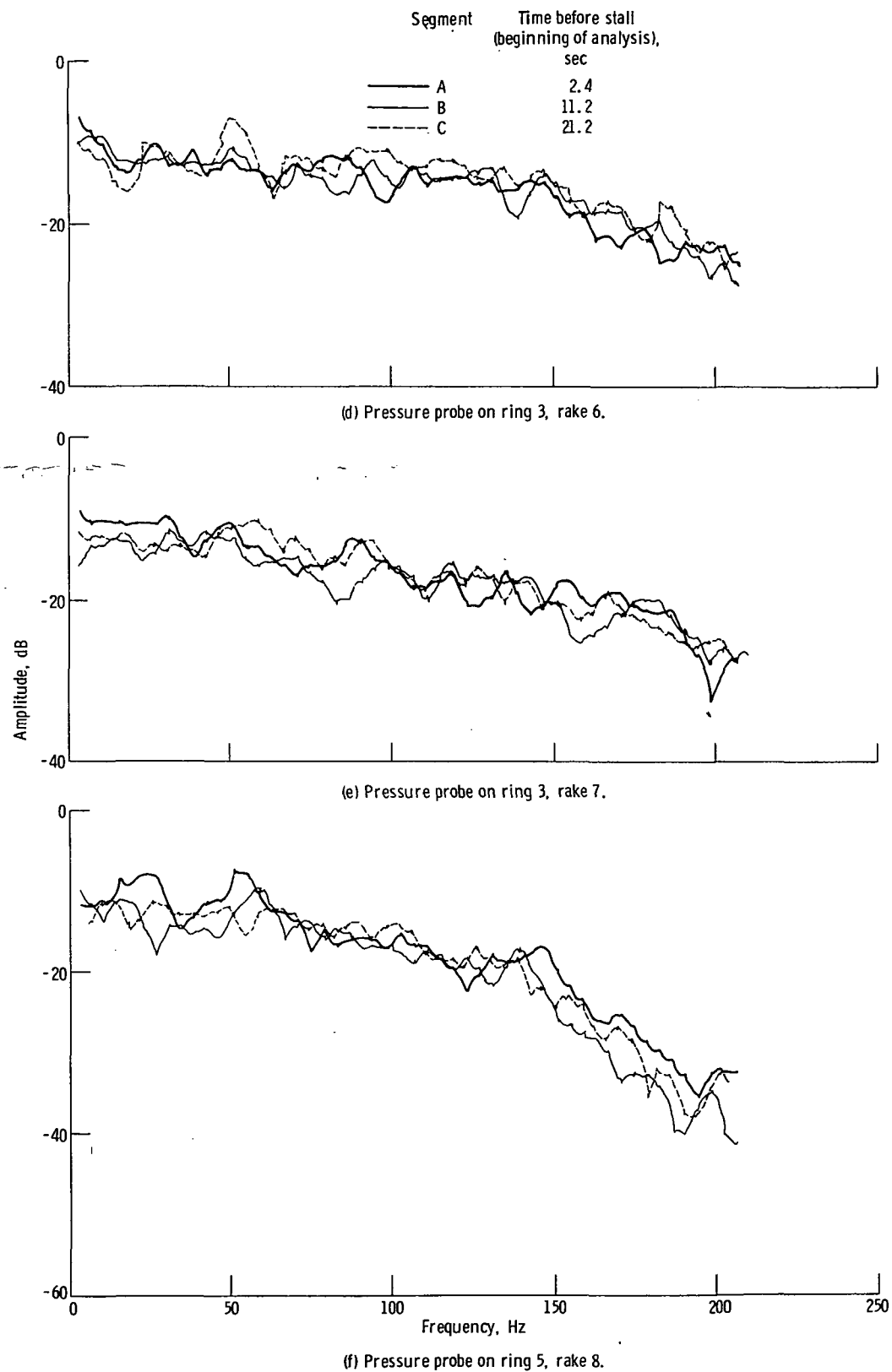


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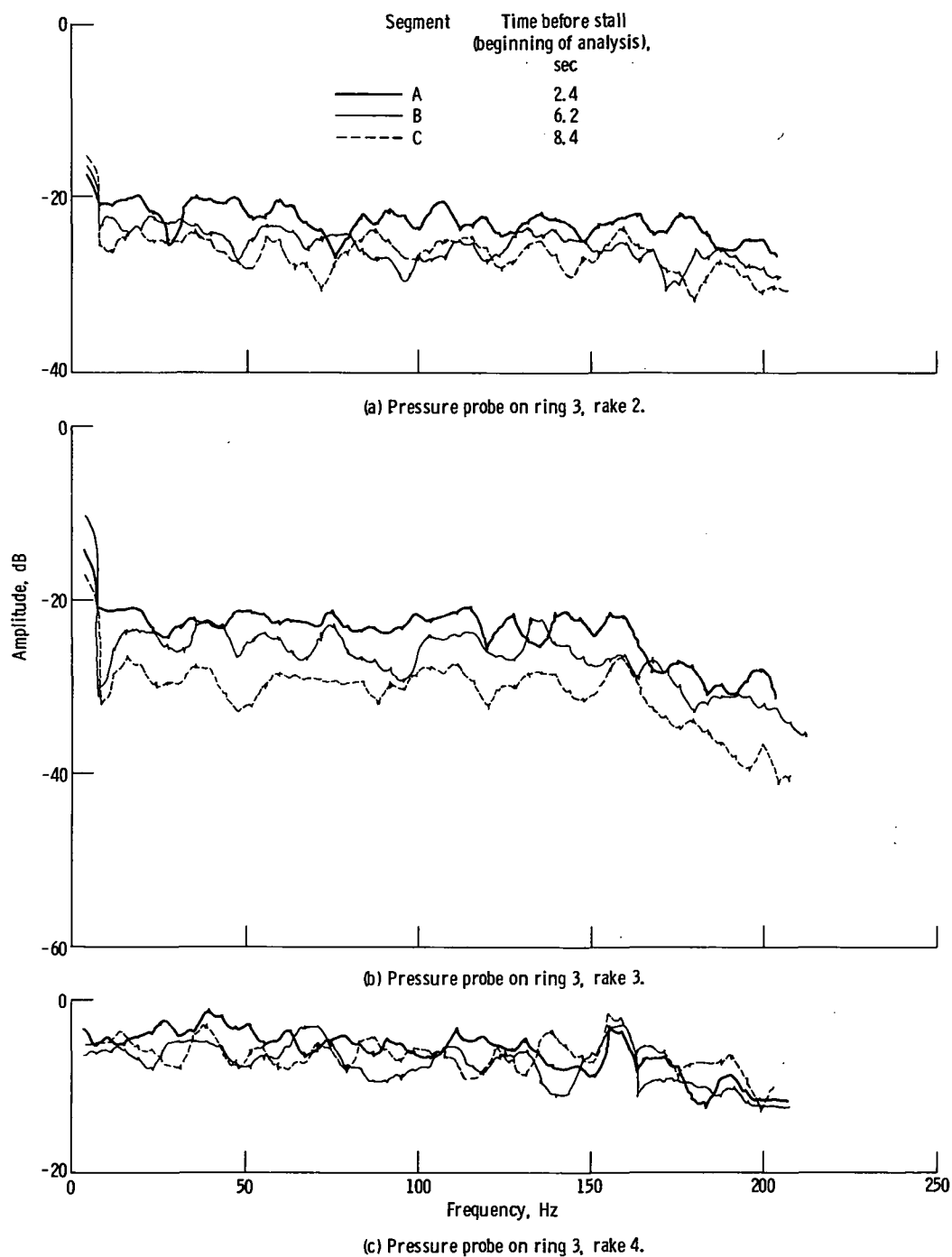


Figure 6. - Power spectra of compressor face total pressures at different times before stall. Flight 43, run 3S; analysis time, 2 seconds; maximum range, 0.220 newton per square centimeter rms (0.316 psi rms).

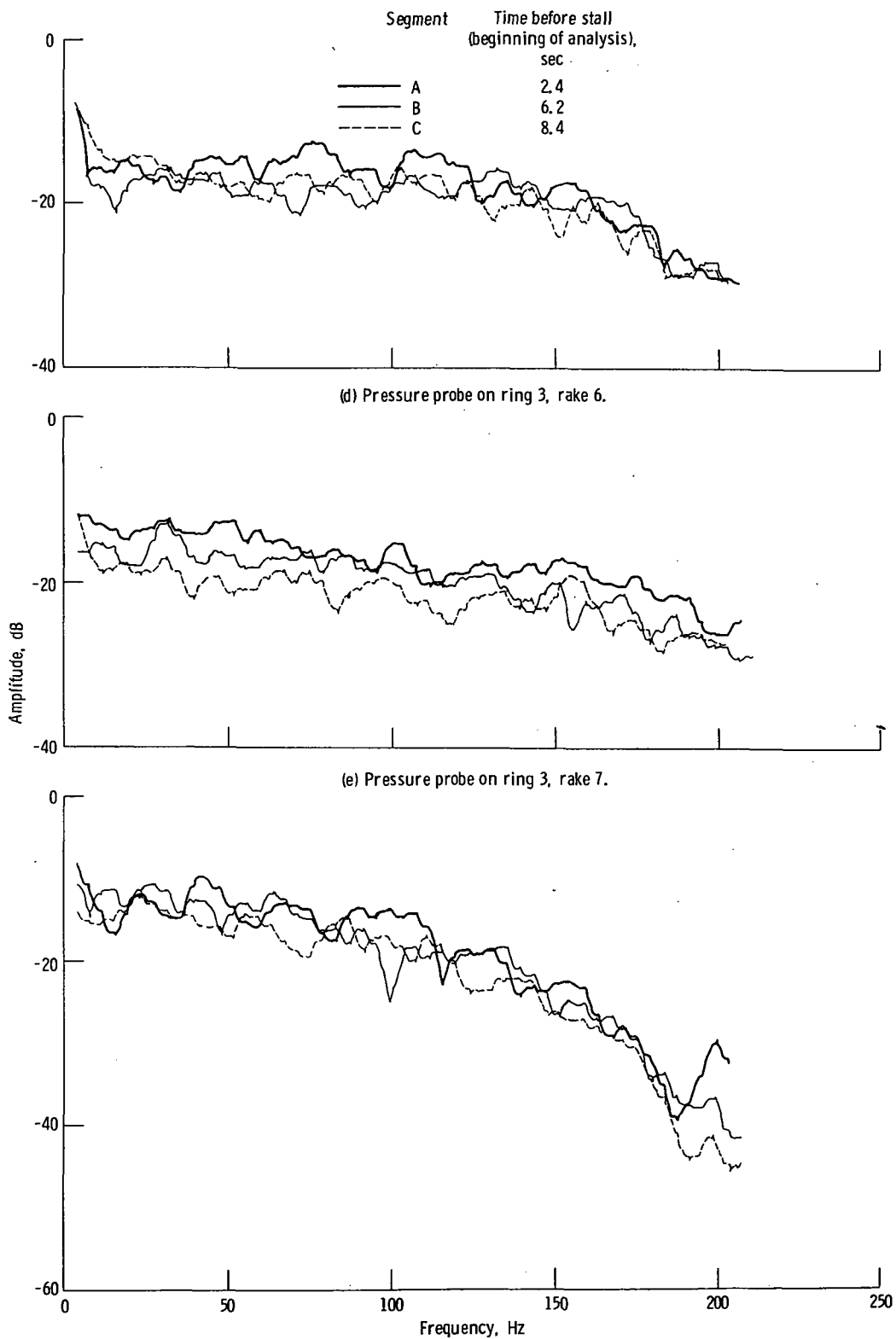


Figure 6. - Concluded.

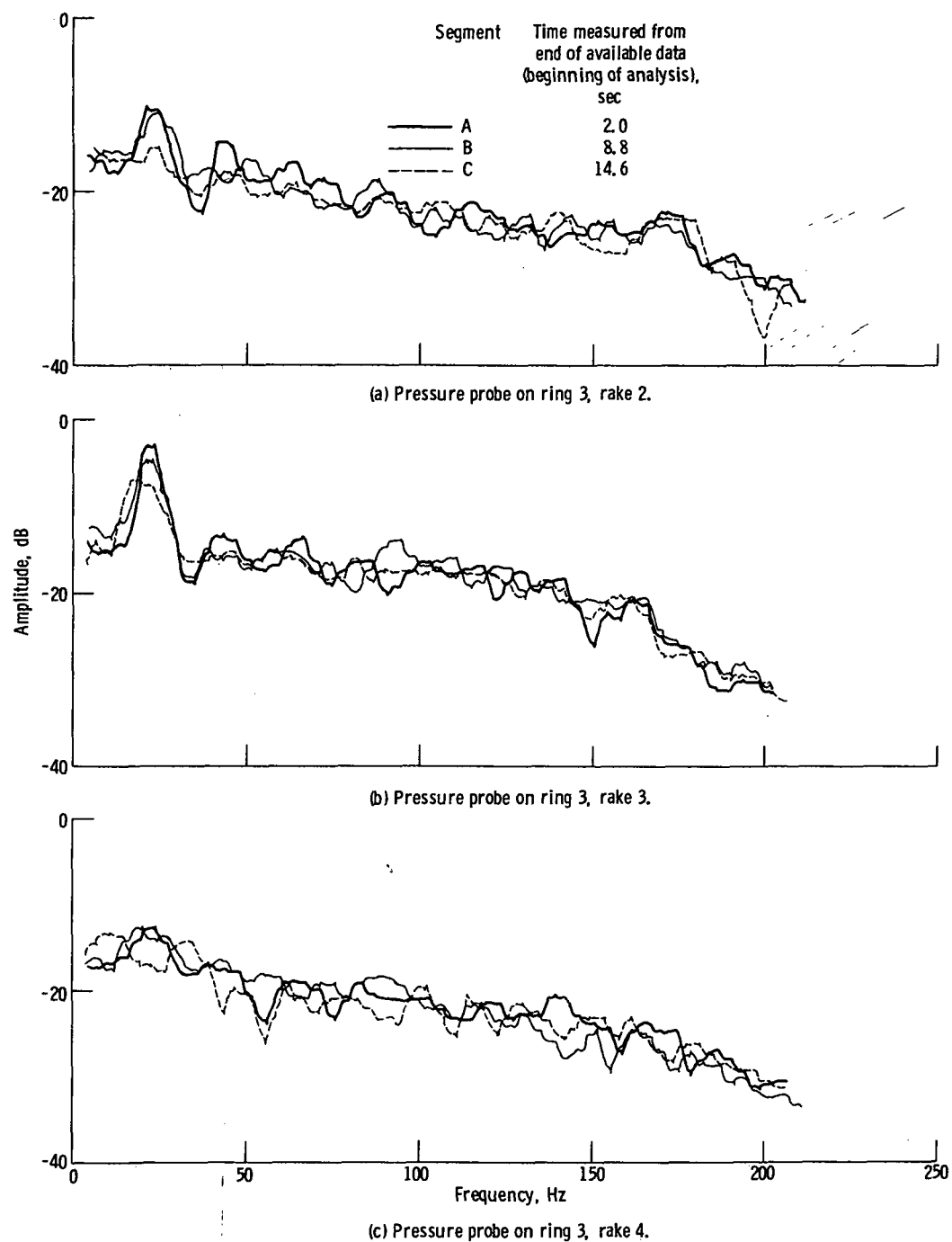


Figure 7. - Power spectra of compressor face total pressures. Flight 45, run 13P2; analysis time, 2 seconds; maximum range, 0.695 newton per square centimeter rms (1.0 psi rms).

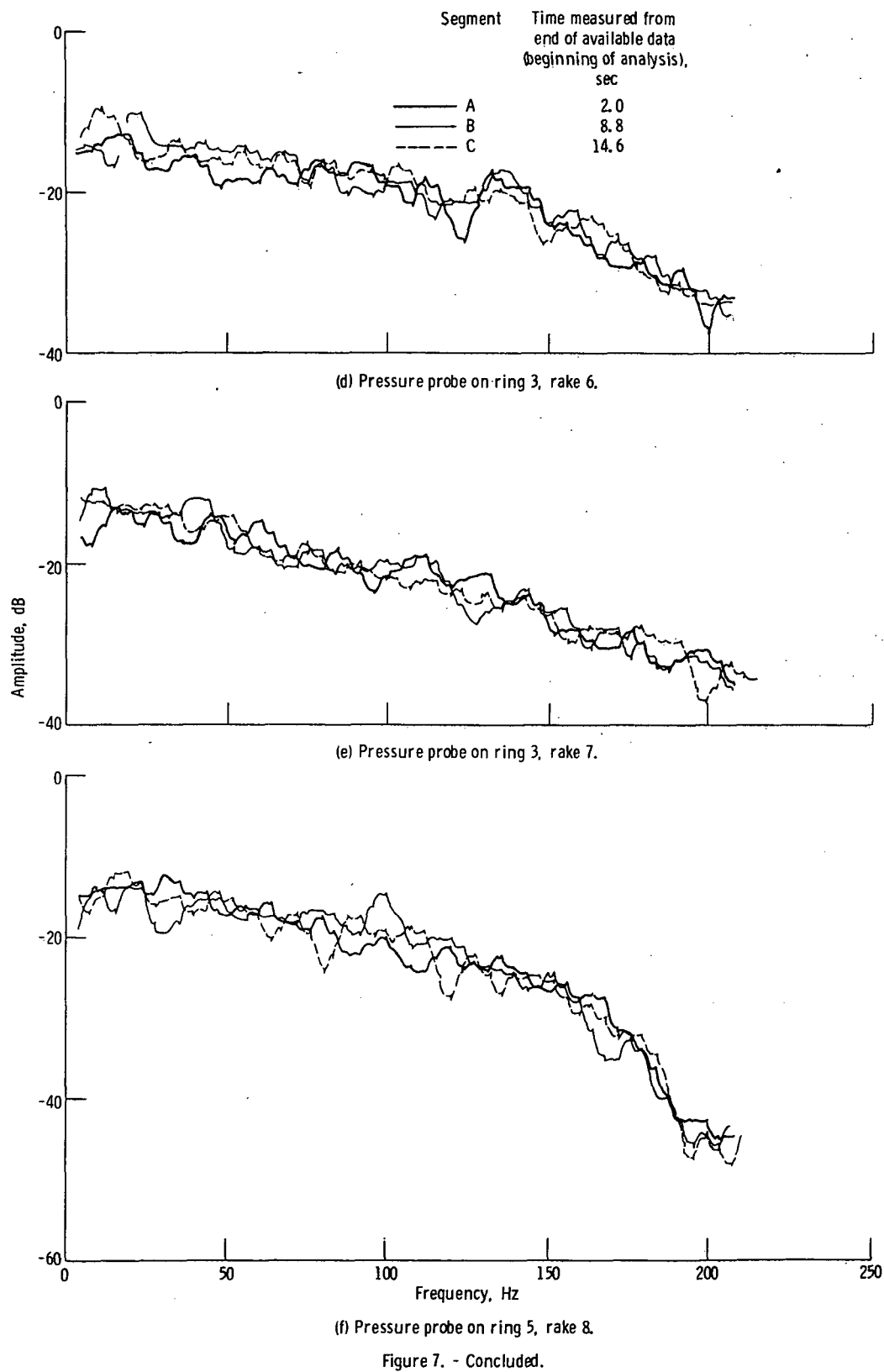
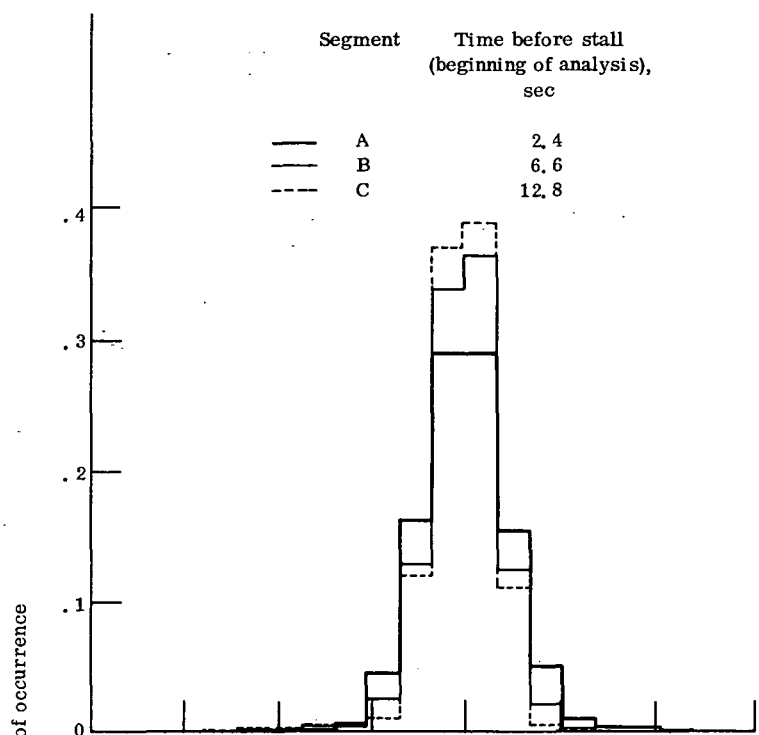
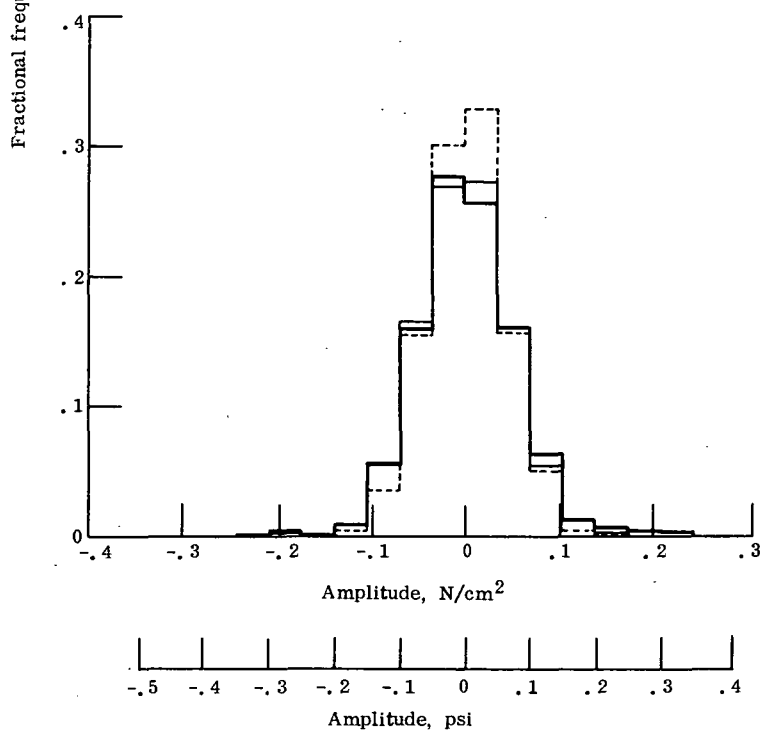


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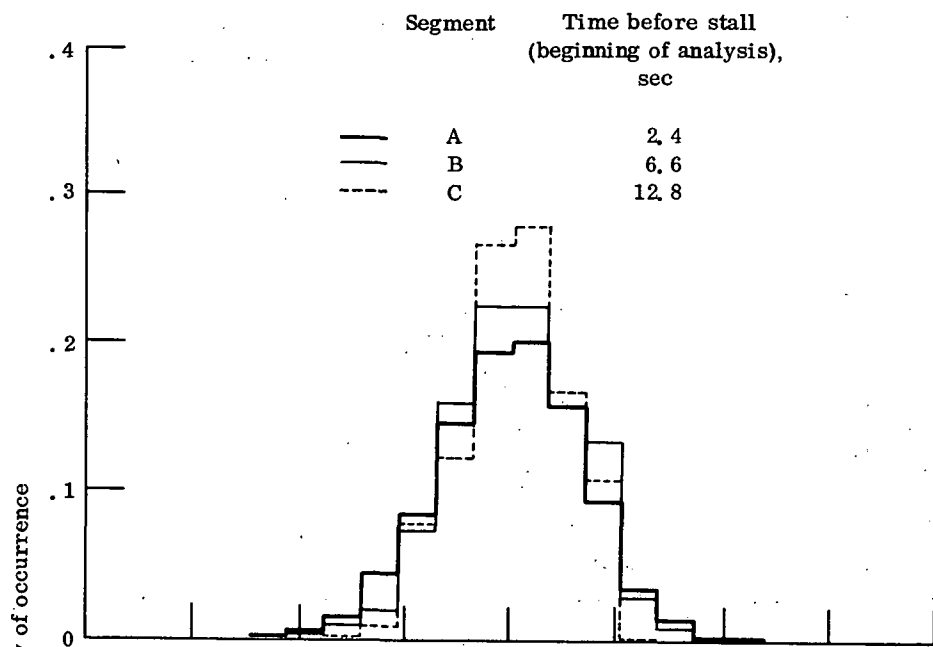


(a) Pressure probe on ring 3, rake 2.

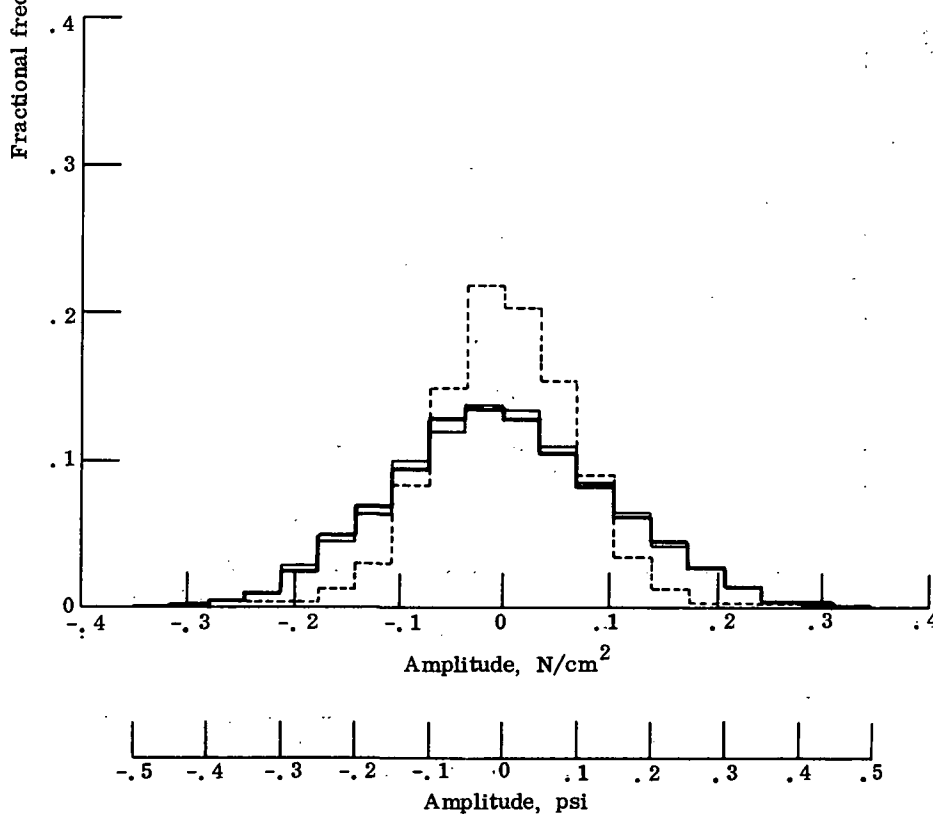


(b) Pressure probe on ring 3, rake 3.

Figure 8. - Histograms of compressor face total pressures at different times before stall. Flight 41, run 11B.

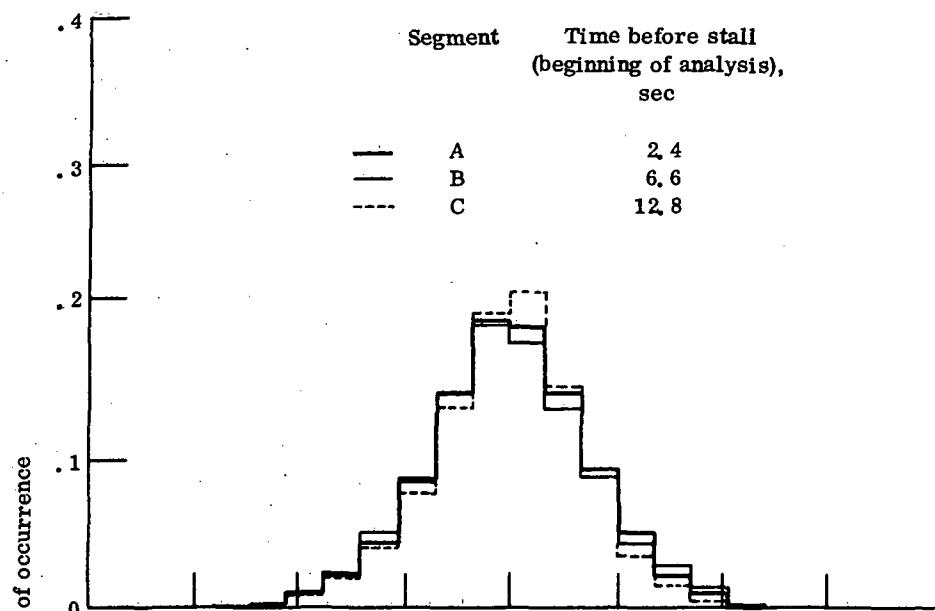


(c) Pressure probe on ring 3, rake 4.

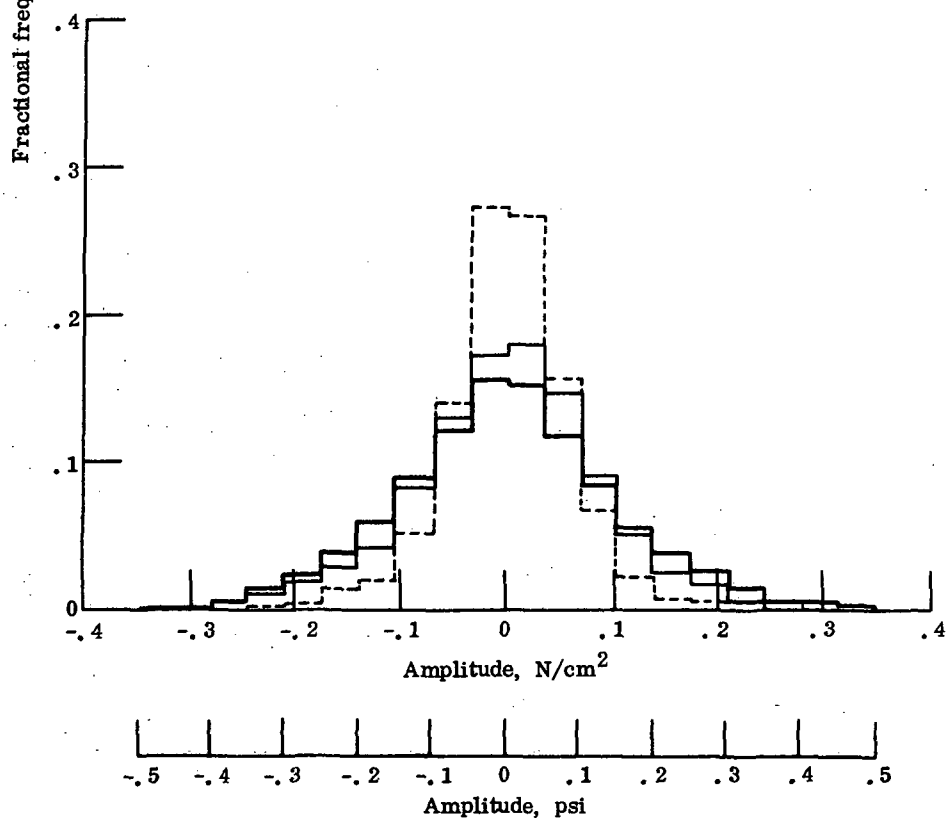


(d) Pressure probe on ring 3, rake 6.

Figure 8. - Continued.

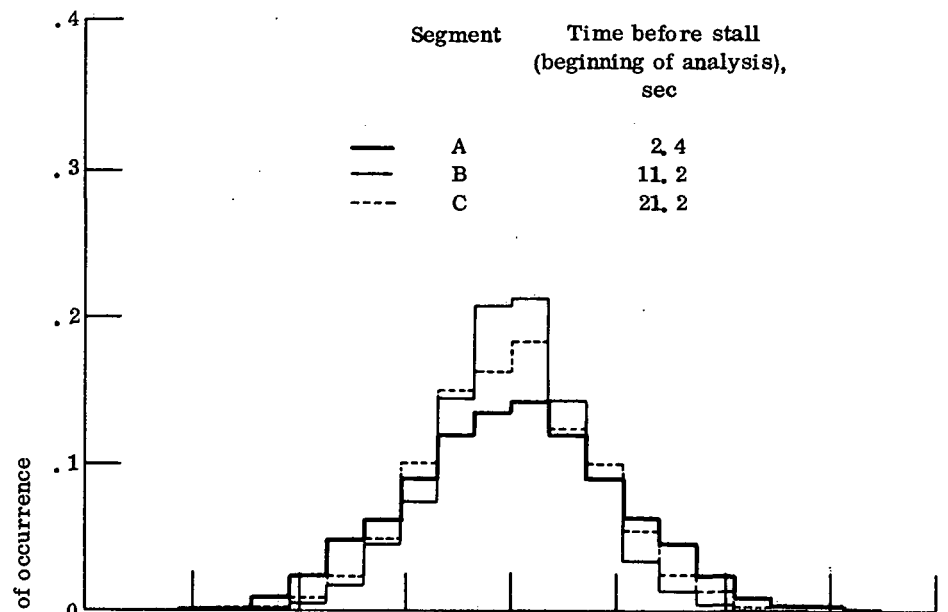


(e) Pressure probe on ring 3, rake 7.

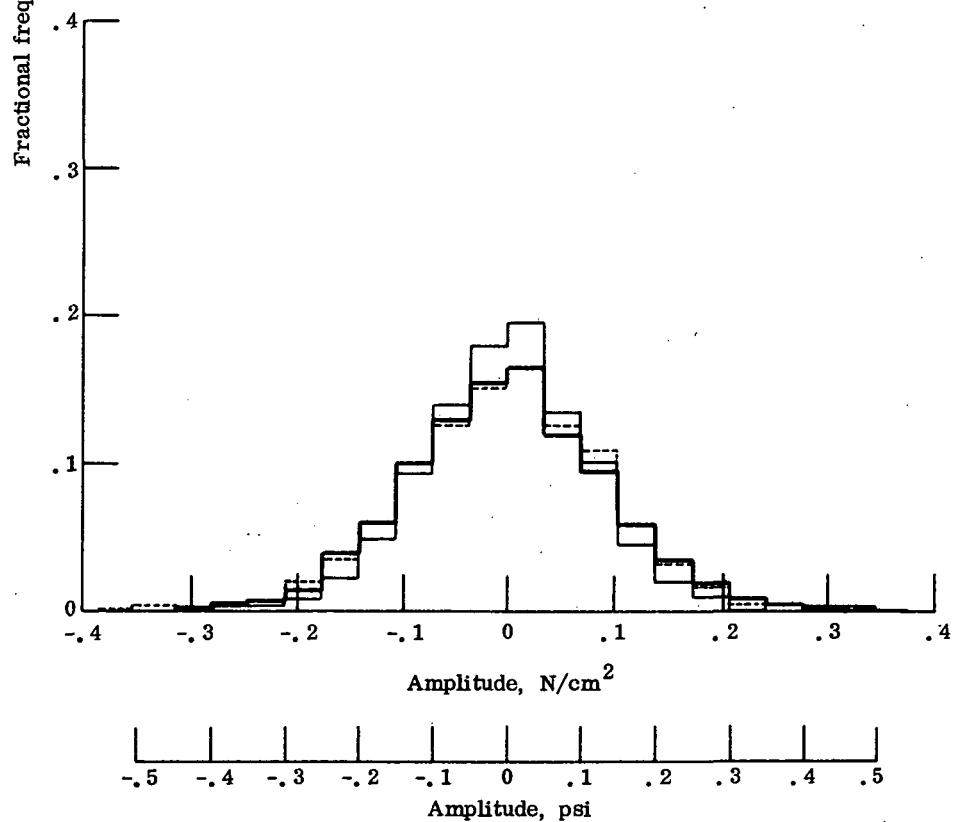


(f) Pressure probe on ring 5, rake 8.

Figure 8. - Concluded.

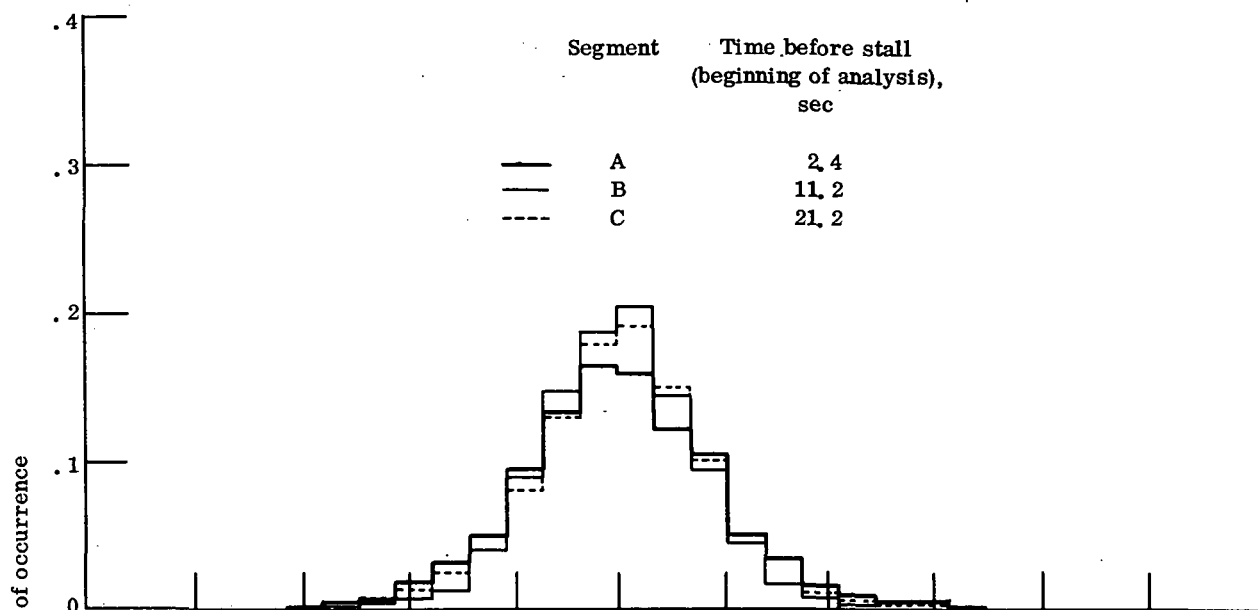


(a) Pressure probe on ring 3, rake 2.

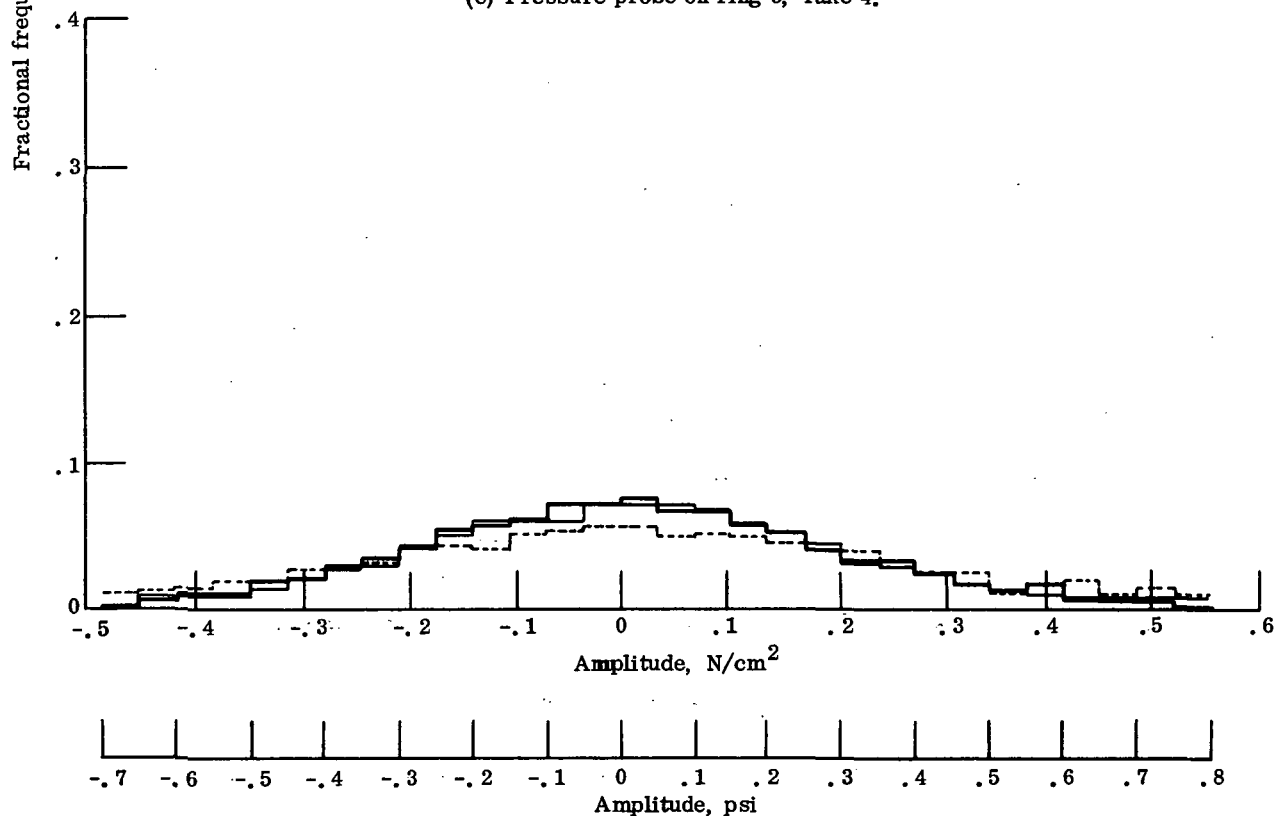


(b) Pressure probe on ring 3, rake 3.

Figure 9. - Histograms of compressor face total pressures at different times before stall, Flight 42, run 1JS.

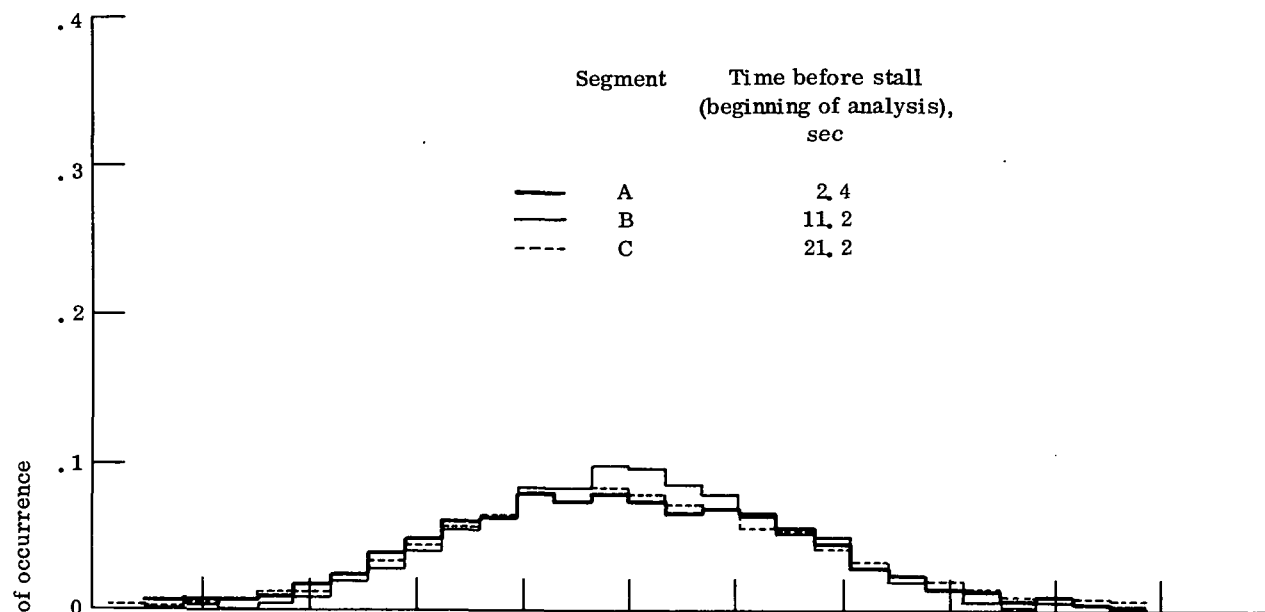


(c) Pressure probe on ring 3, rake 4.

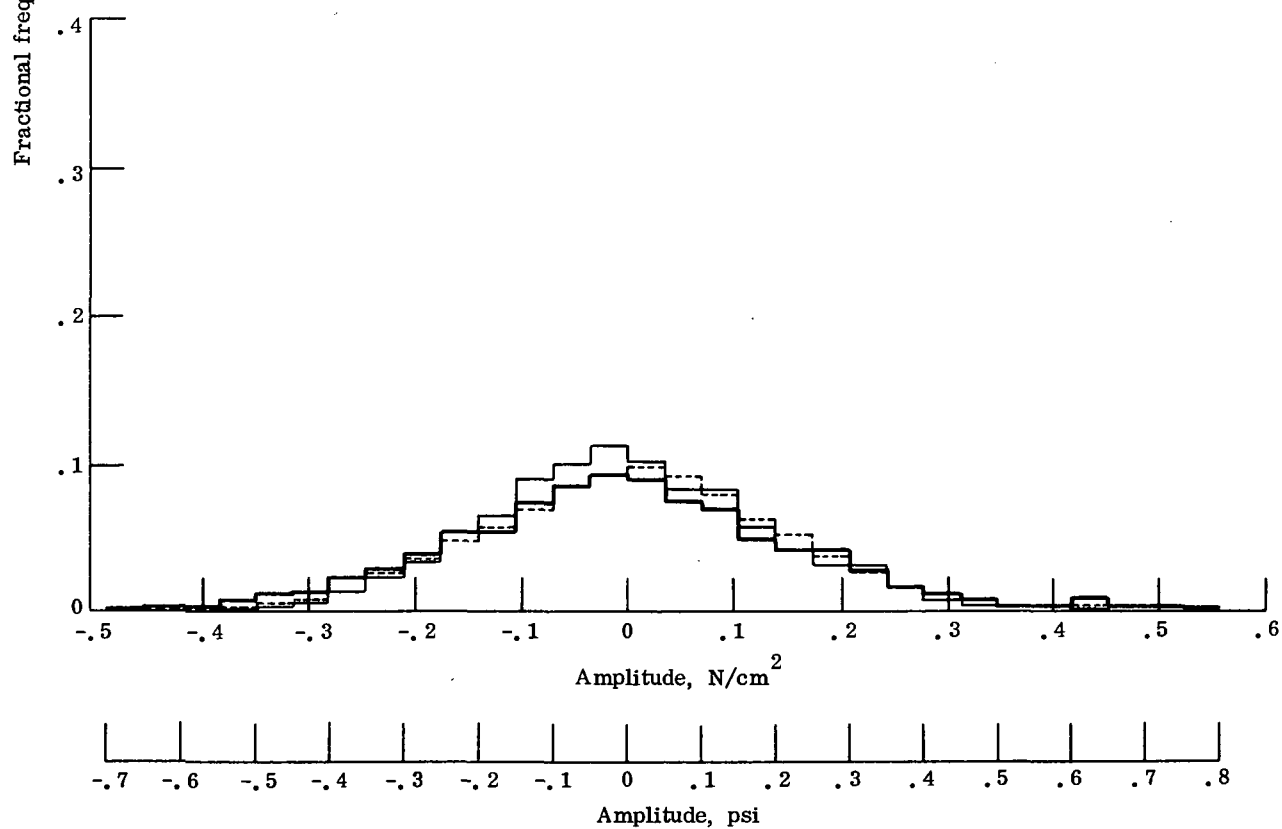


(d) Pressure probe on ring 3, rake 6.

Figure 9. - Continued.



(e) Pressure probe on ring 3, rake 7.



(f) Pressure probe on ring 5, rake 8.

Figure 9. - Concluded.

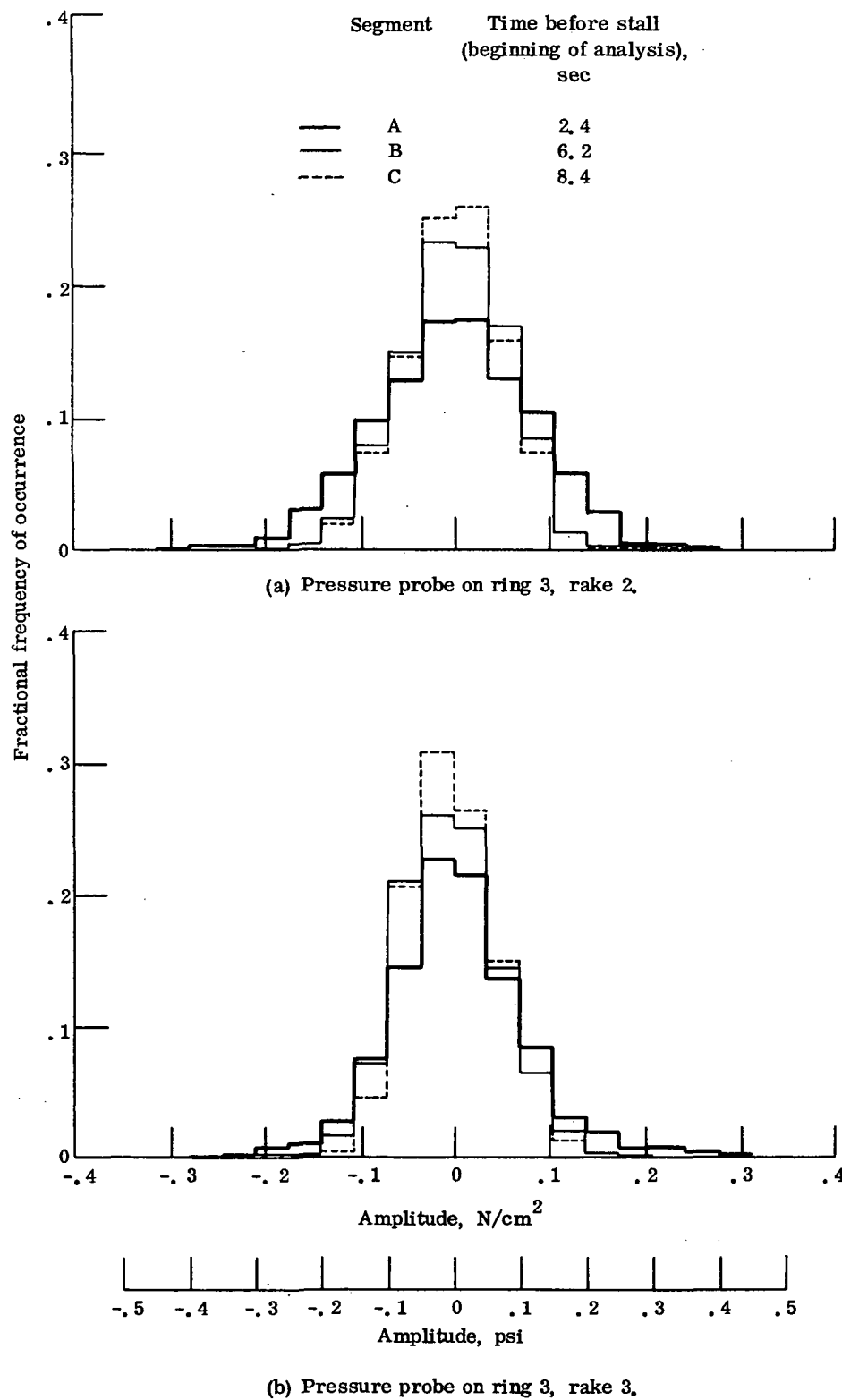
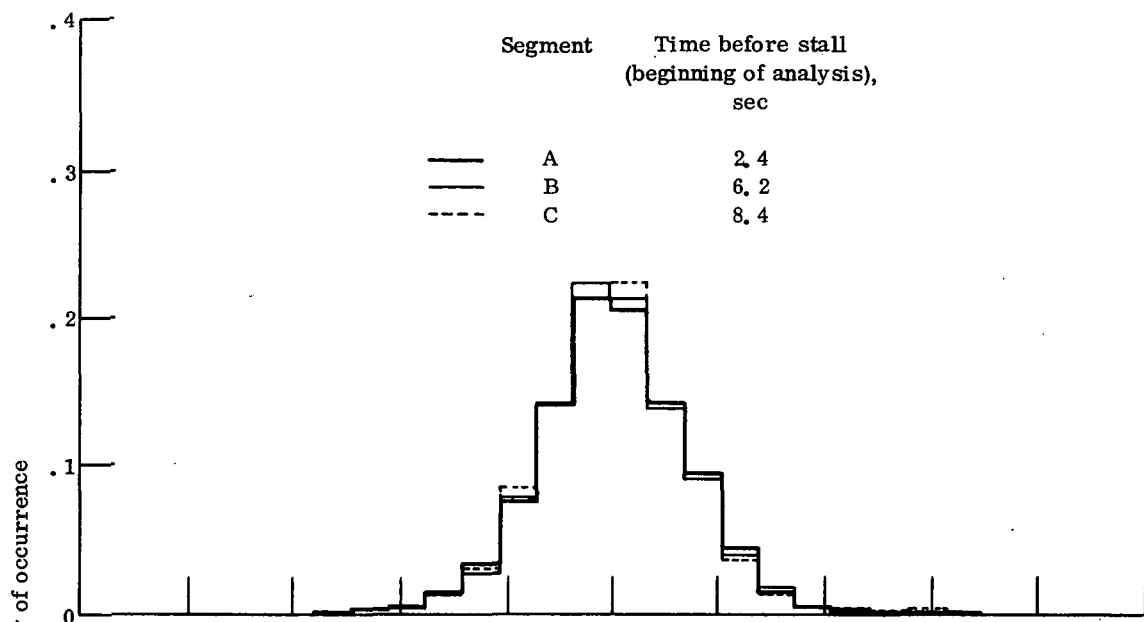
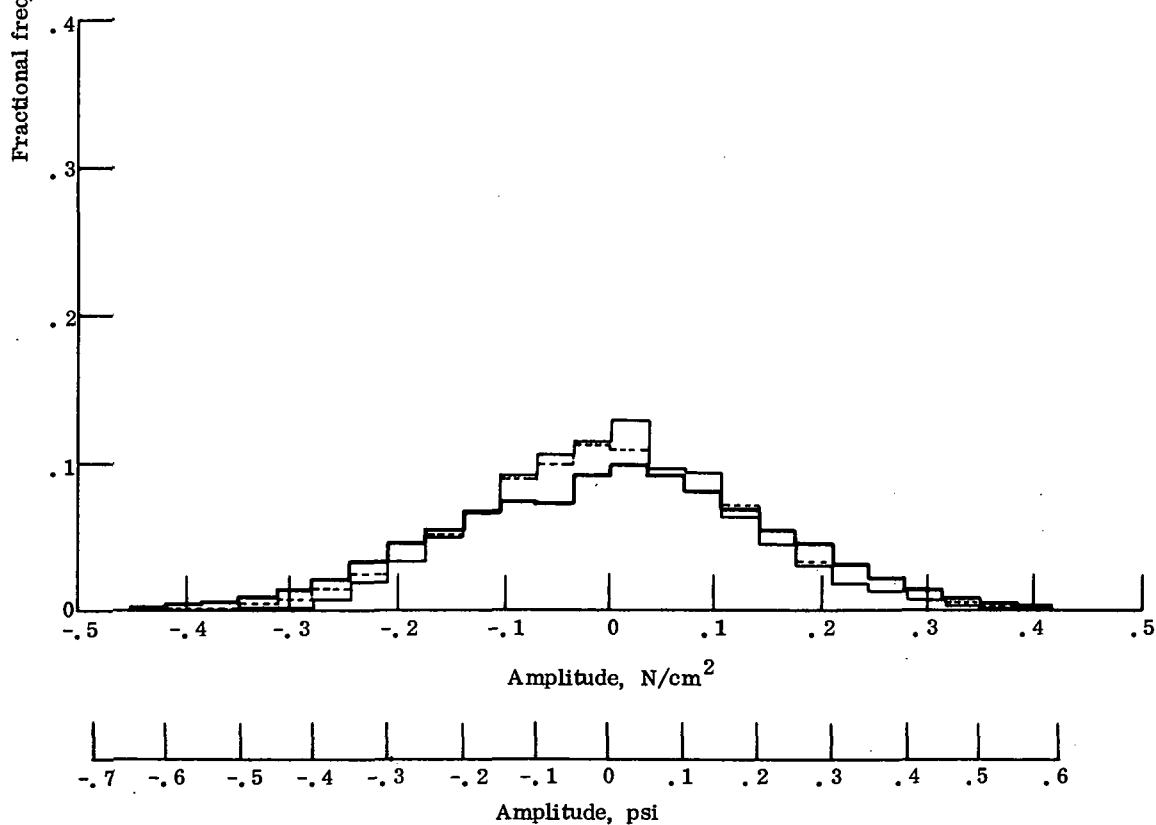


Figure 10. - Histograms of compressor face total pressures at different times before stall, Flight 43, run 3S.

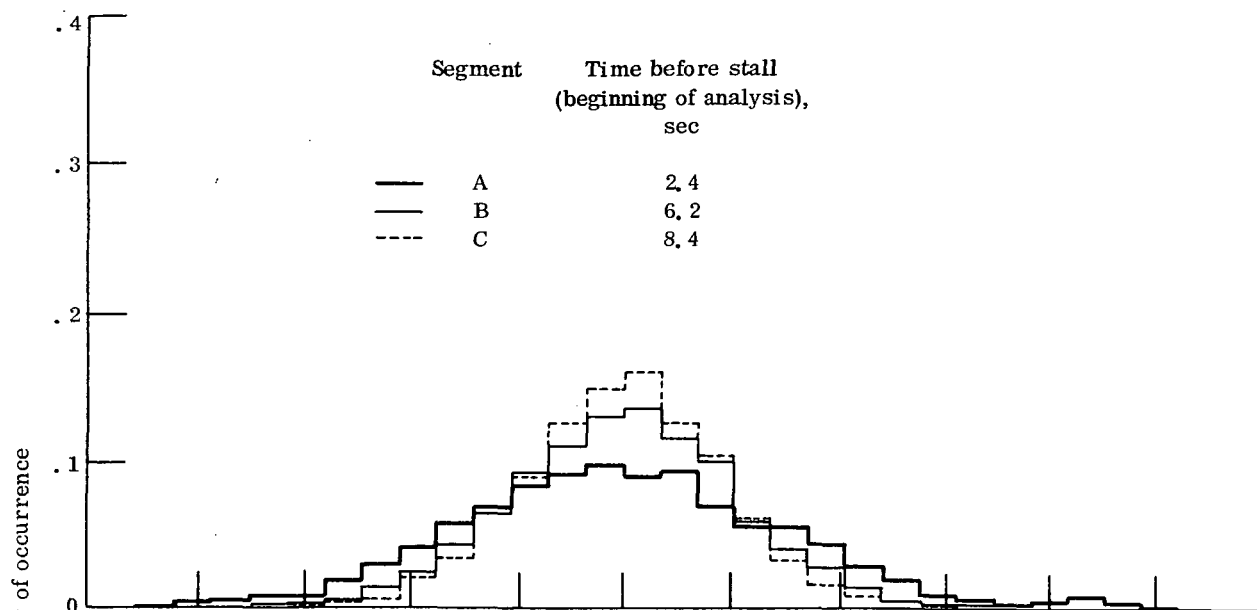


(c) Pressure probe on ring 3, rake 4.

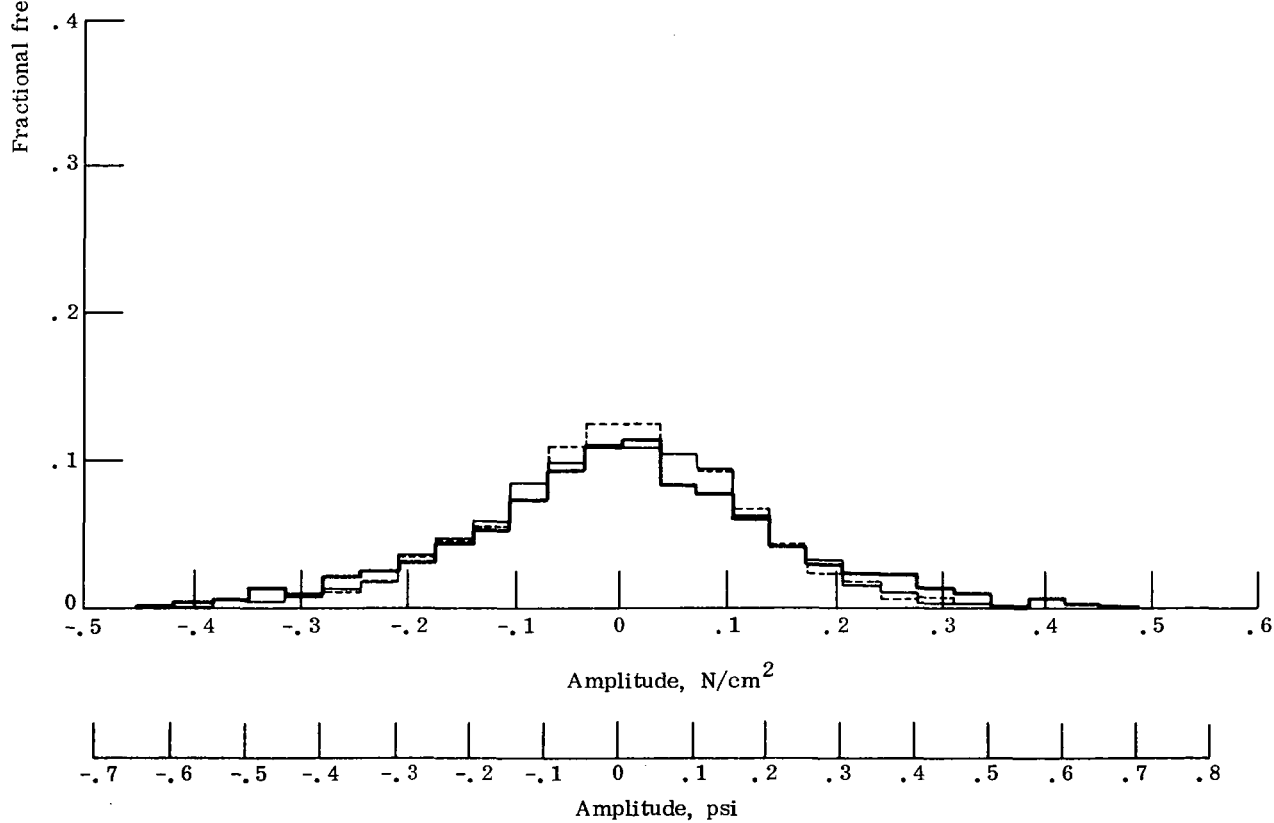


(d) Pressure probe on ring 3, rake 6.

Figure 10. - Continued.

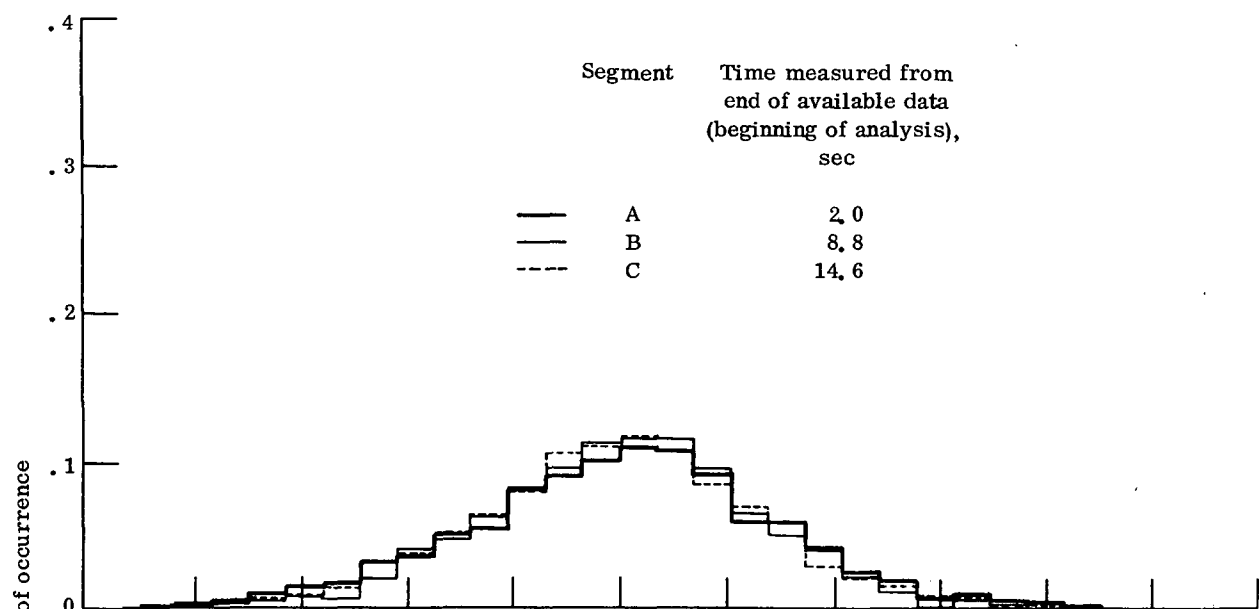


(e) Pressure probe on ring 3, rake 7.

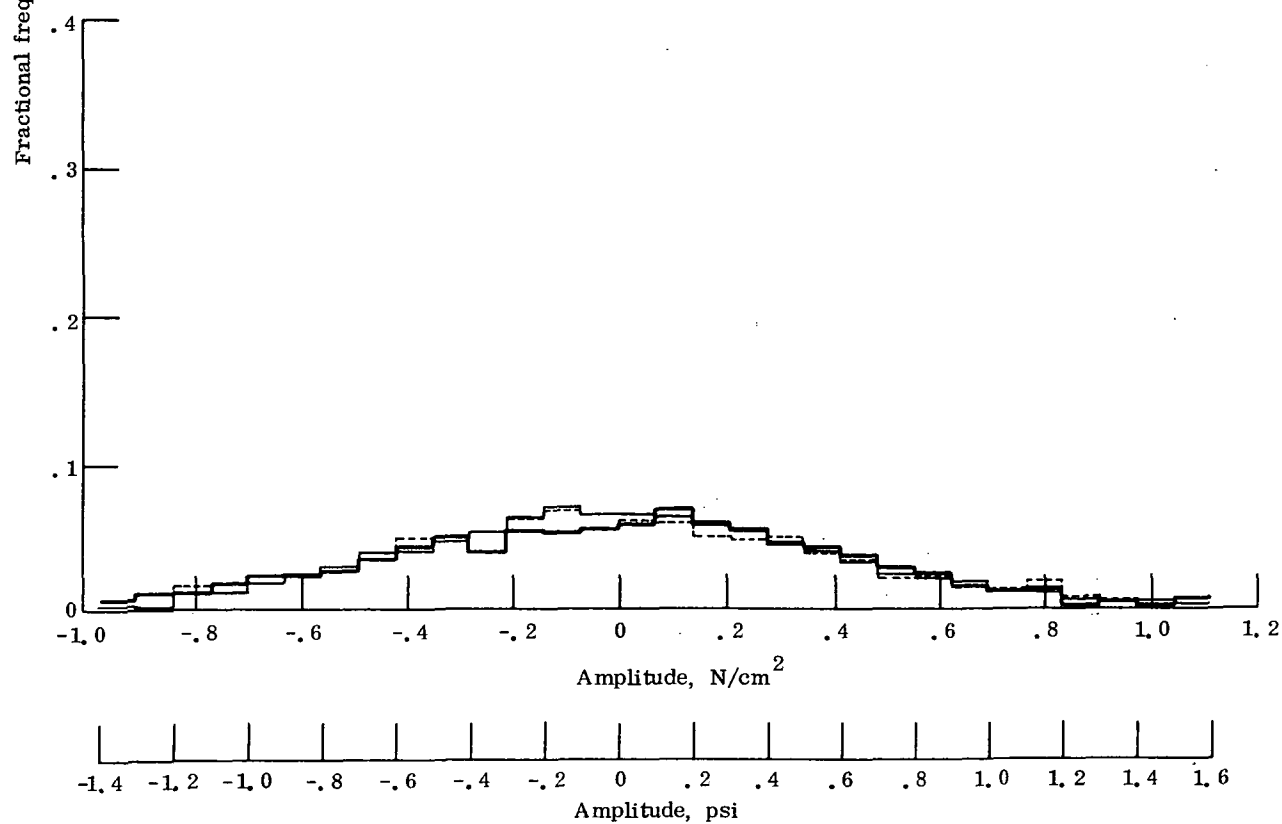


(f) Pressure probe in ring 5, rake 8.

Figure 10. - Concluded.

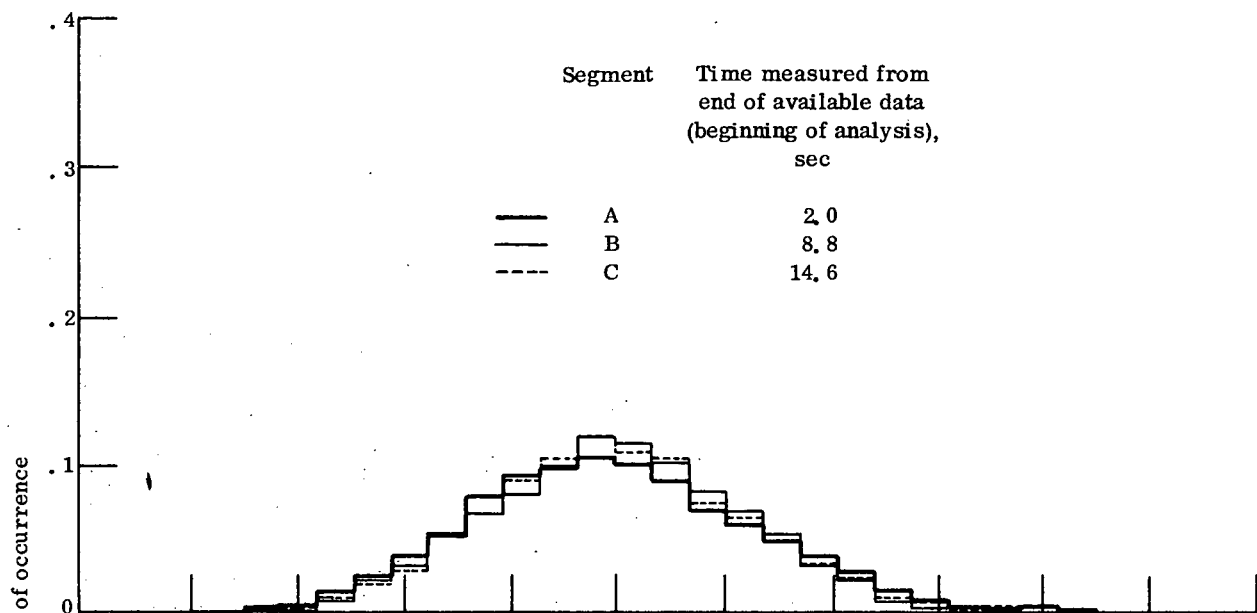


(a) Pressure probe on ring 3, rake 2.

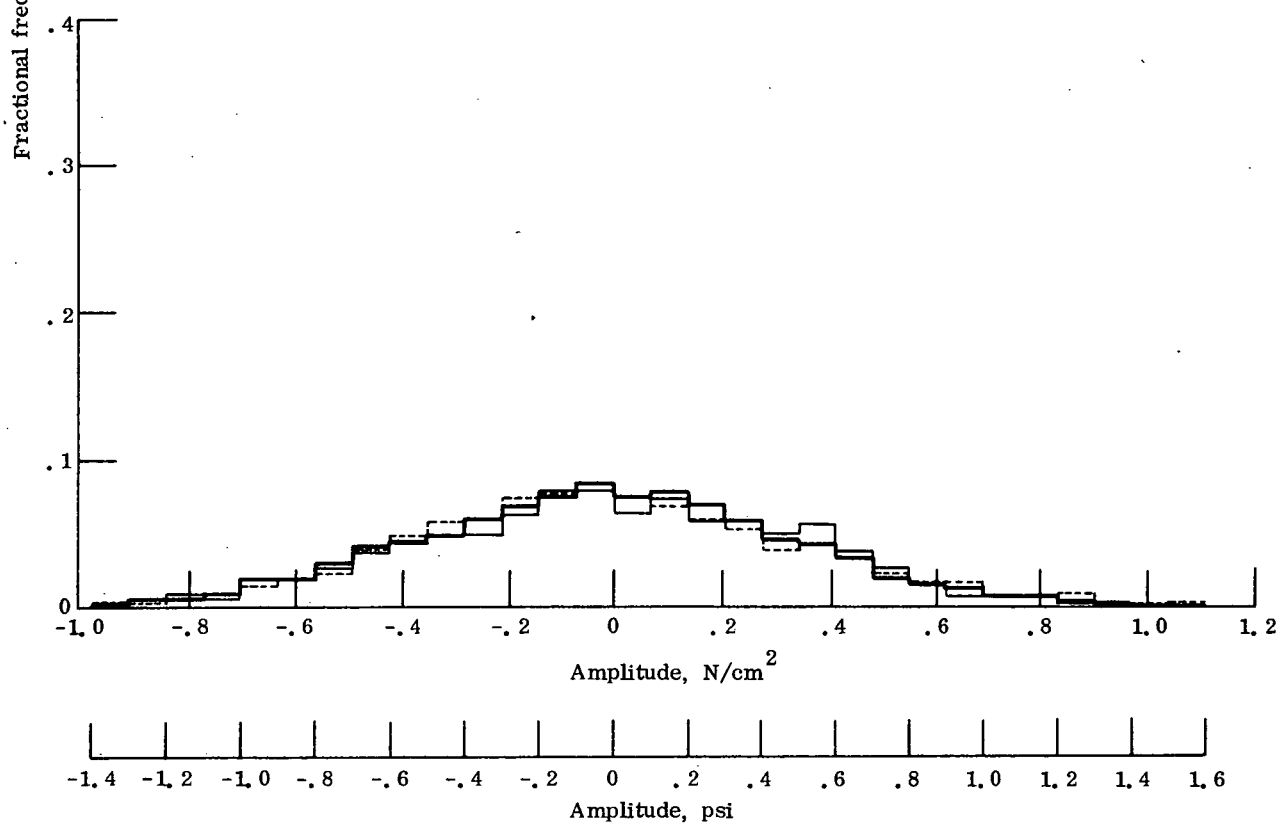


(b) Pressure probe on ring 3, rake 2.

Figure 11. - Histograms of compressor face total pressure at different times before stall. Flight 45, run 13P2.

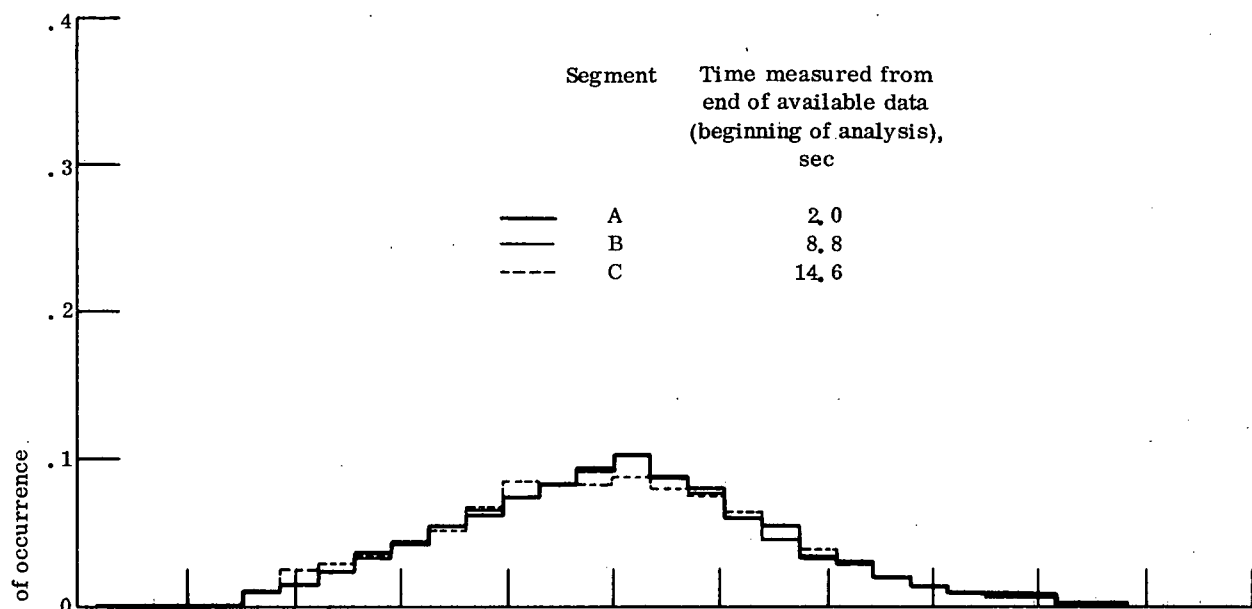


(c) Pressure probe on ring 3, rake 4.

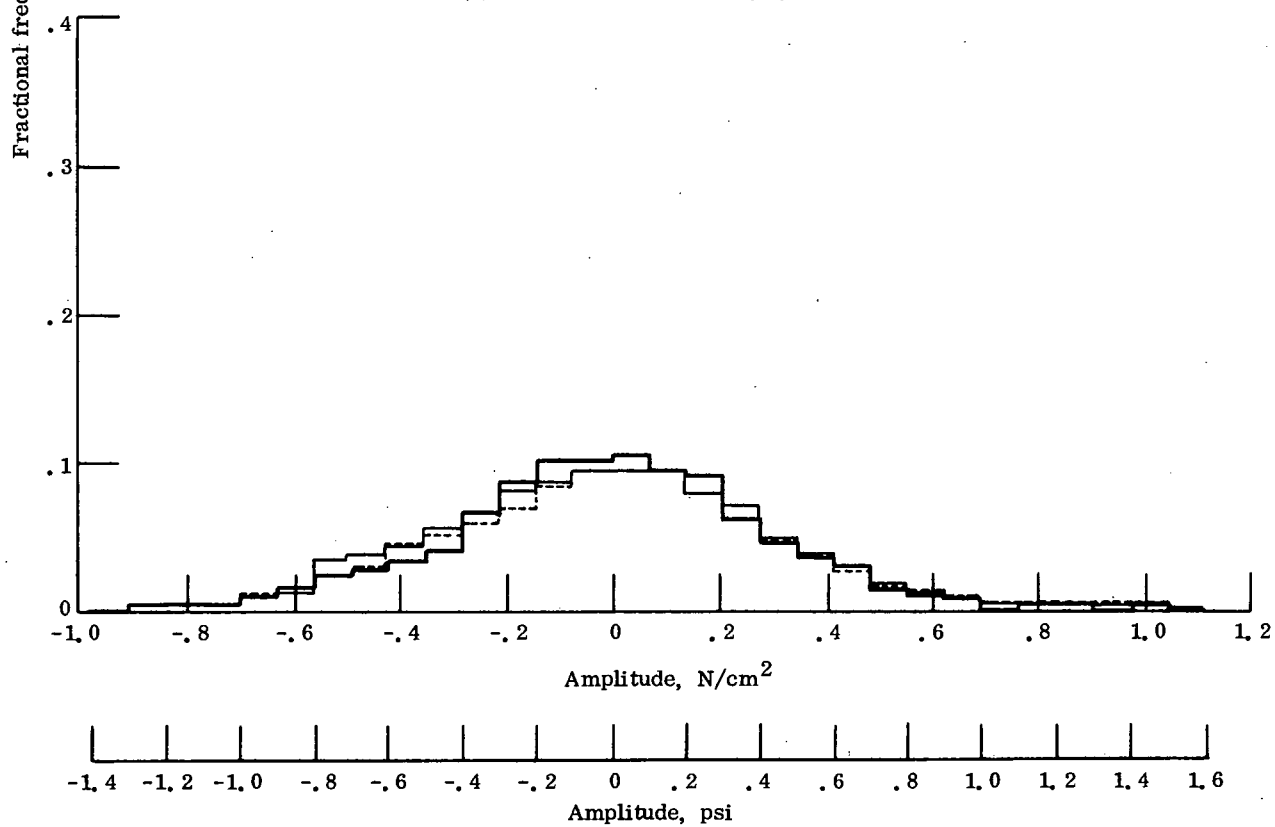


(d) Pressure probe on ring 3, rake 6.

Figure 11. - Continued.

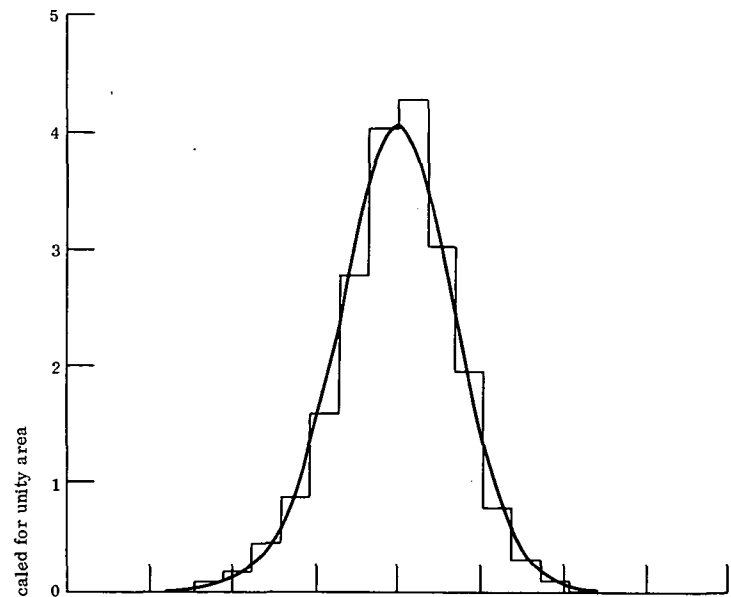


(e) Pressure probe on ring 3, rake 7.

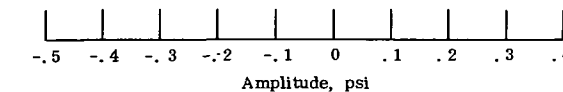
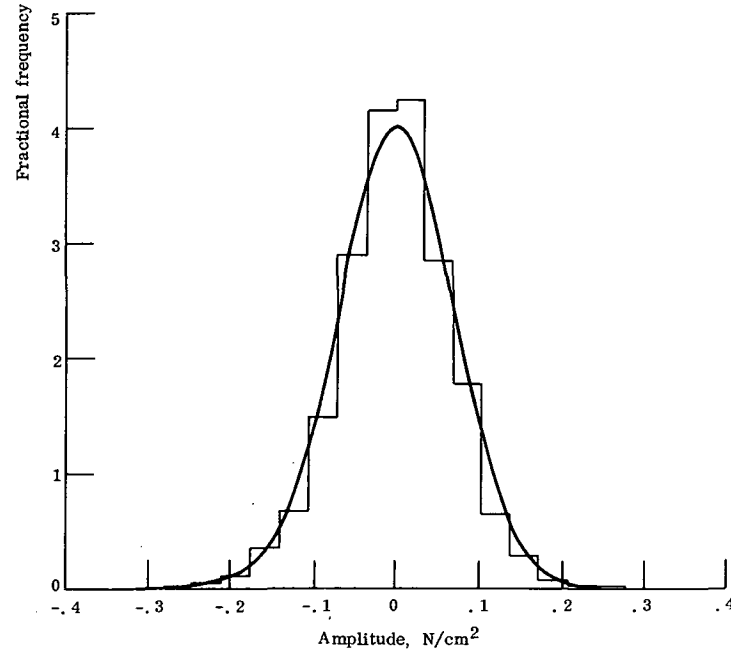


(f) Pressure probe on ring 5, rake 8.

Figure 11. - Concluded.

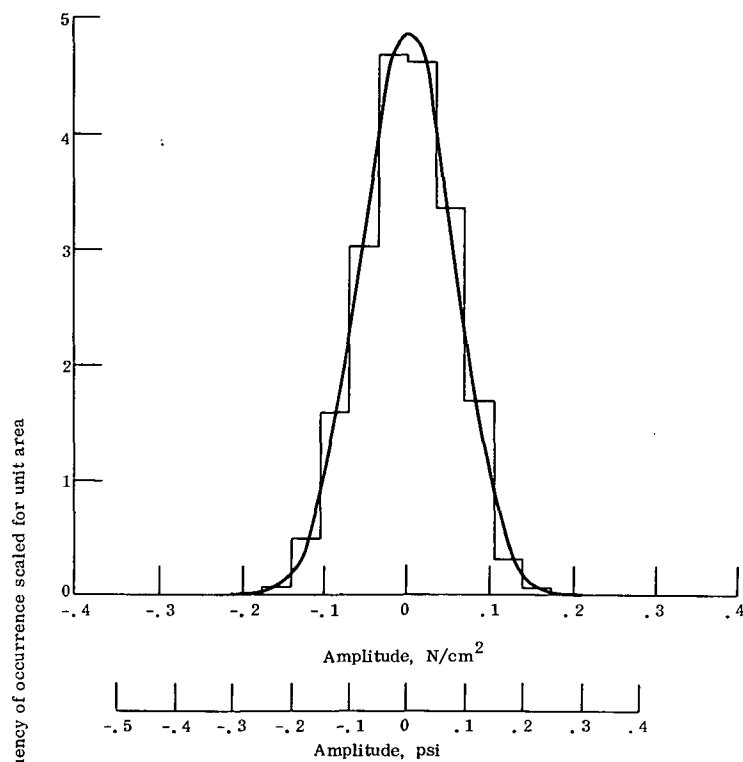


(a) Flight 41, run 11B; probe on ring 3, rake 6; 2-second segment C; mean value, μ , -0.0007 newton per square centimeter (-0.001 psi); standard deviation, σ , 0.069 newton per square centimeter (0.100 psi); kurtosis, β_2 , 3.22; skewness, s , 0.036.

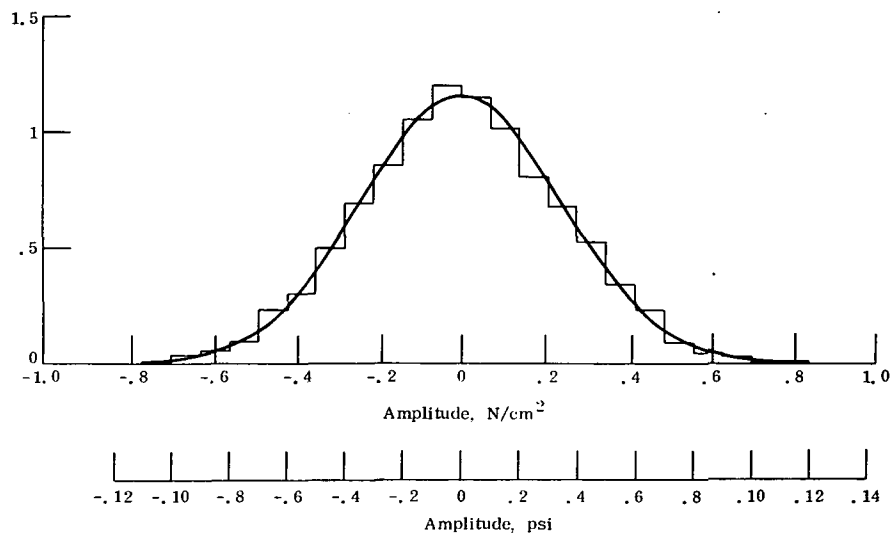


(b) Flight 42, run 1JS; probe on ring 3, rake 2; 2-second segment B; mean value, μ , 0.0014 newton per square centimeter (0.002 psi); standard deviation, σ , 0.069 newton per square centimeter (0.100 psi); kurtosis, β_2 , 3.43; skewness, s , 0.063.

Figure 12. - Fitting of four histograms with Gaussian distributions.



(c) Flight 43, run 3S; probe on ring 3, rake 2; 2-second segment B; mean value, μ , 0.0 newton per square centimeter (0.0 psi); standard deviation, σ , 0.056 newton per square centimeter (0.080 psi); kurtosis, β_2 , 2.86; skewness, s , 0.004.



(d) Flight 45, run 11B; probe on ring 3, rake 4; 2-second segment B; mean value, μ , 0.0007 newton per square centimeter (0.001 psi); standard deviation, σ , 0.239 newton per square centimeter (0.344 psi); kurtosis, β_2 , 2.80; skewness, s , 0.011.

Figure 12. - Concluded.

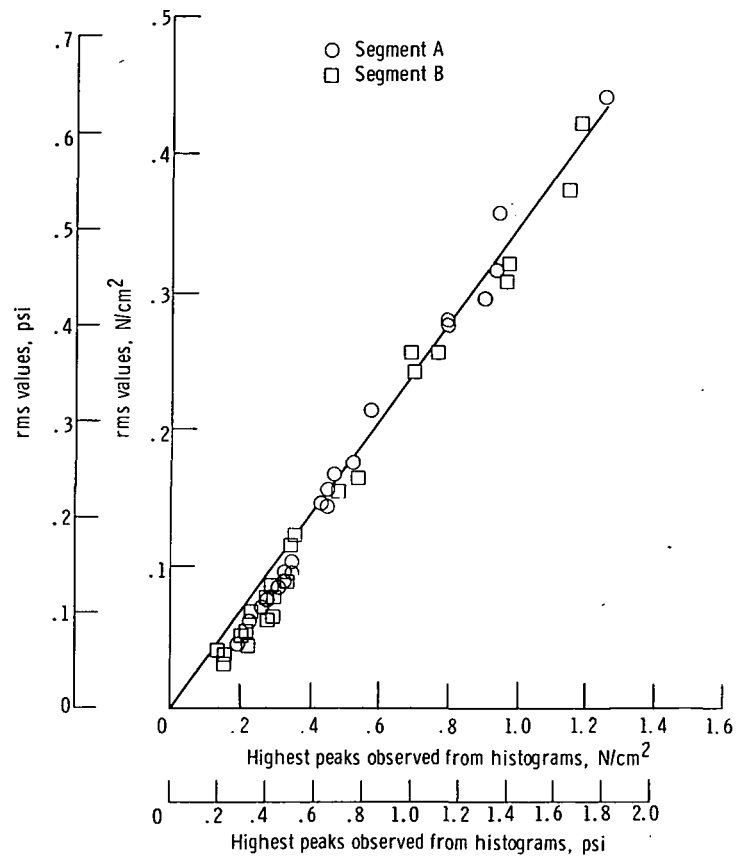


Figure 13. - Correlation between rms values and highest peaks observed.



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